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Versar, Inc., Springfield, VA

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Volume 9

Methods for Estimating Releases of Chemical Substances Resulting from Transportation Accidents

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This report presents methods for calculating expected annual releases of manufactured chemicals resulting from transportation accidents. The scope of the report is limited to releases en route rather than leaks and other releases at transportation terminals. A step-by-step method of calculating annual quantity released per mode of transportation is presented, and sources and limitations of the supporting data are discussed in detail. This method is suitable for comparing estimates of annual releases of several chemicals or for comparing releases by various modes of transportation for one chemical.

A statistical analysis of the Department of Transportation (DOT) HAZMAT data base is included as an appendix to the report. The analysis focuses on differences in the expected fraction of shipment released or fraction of container released based on mode of transportation and type of chemical.

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Volume 9

Methods for Estimating Releases of Chemical Substances Resulting from Transportation Accidents

by

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FOREWORD

This document is one of a series of volumes, developed for the U.S. Environmental Protection Agency (EPA), Office of Toxic Substances (OTS), that provides methods and information useful for assessing exposure to chemical substances. The methods described in these volumes have been identified by EPA-OTS as having utility in exposure assessments on existing and new chemicals in the OTS program. These methods are not necessarily the only methods used by OTS, because the state of the art in exposure assessment is changing rapidly, as is the availability of methods and tools. There is no single correct approach to performing an exposure assessment; thus, the methods in these volumes are discussed only as options to be considered rather than as rigid procedures to be followed.

Unlike other volumes in this series, this report does not present exposure calculations based on incident- or source-specific release scenarios. Instead, it deals with a broad category of source information annual releases of chemicals by various modes of transportation. Exposure assessment methods for individual vehicular accidents involving chemicals may be addressed in a future volume.

The definition, background, and discussion of planning exposure assessments are discussed in the introductory volume of the series (Volume 1). Each subsequent volume addresses only one general exposure setting. Consult Volume 1 for guidance on the proper use and interrelations of the various volumes and on the planning and integration of an entire assessment.

The titles of the nine basic volumes are as follows:

Volume 1	Methods for Assessing Exposure to Chemical Substances (EPA 560/5-85-001) (PB86-107083)
Volume 2	Methods for Assessing Exposure to Chemical Substances in the Ambient Environment (EPA 560/5-85-002) (PB86-107067)
Volume 3	Methods for Assessing Exposure from Disposal of Chemical Substances (EPA 560/5-85-003) (PB86-107059)
Volume 4	Methods for Enumerating and Characterizing Populations Exposed to Chemical Substances (EPA 560/5-85-004) (PB86-107042)
Volume 5	Methods for Assessing Exposure to Chemical Substances in Drinking Water (EPA 560/5-85-005) (PB86-1232156)

Volume 6	Methods for Assessing Occupational Exposure to Chemical Substances (EPA 560/5-85-006) (PB86-157211)
Volume 7	Methods for Assessing Consumer Exposure to Chemical Substances (EPA 560/5-85-007)
Volume 8	Methods for Assessing Environmental Pathways of Food Contamination (EPA 560/5-85-008)
Volume 9	Methods for Estimating Releases of Chemical Substances Resulting from Transportation Accidents (EPA 560/5-85-009).

EPA-OTS intends to issue periodic supplements for Volumes 2 through 9 to describe significant improvements and updates to the existing information. The Agency also plans to add short monographs to the series dealing with specific areas of interest. The first four monographs to be added are as follows:

Volume 10	Methods for Estimating Uncertainties in Exposure Assessments (EPA 560/5-85-014)
Volume 11	Methods for Estimating the Migration of Chemical Substances from Solid Matrices (EPA 560/5-85-015)
Volume 12	Methods for Estimating the Concentration of Chemical Substances in Indoor Air (EPA 560/5-85-016)
Volume 13	Methods for Estimating Retention of Liquids on Hands (EPA 560/5-85-017)

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A number of Versar personnel have contributed to this task over the period of performance. These individuals are shown below:

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1. INTRODUCTION

This report explains how to develop quantitative information on annual expected releases of manufactured chemicals between the point of origin (i.e., manufacturing location) and the point of first delivery in commerce. The data generated (that is, the expected number of releases and total quantity released annually) are useful in analyses of chemicals transportation. Examples of appropriate uses of this information are: (1) to compare expected releases of alternative chemicals that would be shipped routinely from a manufacturer for a particular use, or (2) to weigh the effects of potential releases associated with one mode of transportation with those related to another mode for the same chemical.

1.1 Purpose and Scope

The purpose of this report is to present methods of calculating the expected annual release of individual chemicals resulting from transportation-related accidents. The methods are based on historical patterns of chemical shipments and accidental releases of those chemicals. Methods of calculation are presented for releases by each of four major transportation modes (truck, rail, air, and waterborne transport*).

The scope of this report and the methods described are limited to manufactured chemicals when distributed in commerce and to accidental releases occurring en route, that is, between terminal points. Because of these limitations, the methods do not include calculations of releases occurring during loading and unloading, although hazardous material releases do occur during these activities as well as en route (ICF 1984, OTA 1986). Limiting of this report to manufactured chemicals means that some hazardous material groups regulated by the U.S. Department of Transportation (DOT) and the U.S. Environmental Protection Agency (EPA), such as etiological agents, explosives, crude oil, and hazardous waste, are not included. In addition, pipelines have not been considered along with the other modes of transportation.

1.2 Structure of the Report

Because this report focuses on a method of calculation, much of the text is devoted to explaining how required information on shipping patterns and accident statistics can be accessed and used in this method. Section 1.3 discusses the primary sources of data used in this report and their limitations. A brief overview of manufactured chemical shipping patterns in the United States, and the causes of chemical releases during transportation, are presented in Section 2. The body of the method is contained in Section 3. This section presents a step-by-step method of calculating the expected quantity of a chemical that may be released annually during transportation accidents. Because some steps of the method cite optional data sources and methods of application, examples are given to demonstrate those options.

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* At present, available data are insufficient to predict chemical releases from waterborne transport.

The appendices provide supplementary information that is used in performing the calculations described in Section 3. A description of the U.S. Department of Transportation (DOT) hazard classes of chemicals is contained in Appendix A, and a statistical analysis of historical transportation-related release data that was performed for this report is discussed in Appendix B. This statistical analysis focuses on the significance of the physical state of the chemical, the DOT hazard class, and the mode of transportation as those factors contributing to the quantity of a chemical released when an accident occurs. Appendix C presents methods of estimating average shipping distances of chemicals.

1.3 Sources of Information

An analysis of accidental releases of a chemical distributed in commerce requires information on commodity shipping patterns, namely, the quantities of that chemical shipped and the average shipping distances by various modes of transportation. Historical accident and release data on the chemical, or a class of chemicals, are also needed to project frequencies and quantities released.

At this time, U.S. commodity shipping data and historical accident data are not archived in one system, nor are the available records stored by one classification scheme. Rather, these data are compiled by various federal agencies and private industry organizations in distinct data bases, and the reader will need to consult a number of references in order to complete the calculations described in Section 3.

To illustrate the variety of information sources needed to establish shipping and accident patterns, several key sources of information that were consulted in the preparation of this report are described briefly below. The use of each of these sources of information is explained in detail in the description of the methods presented in Section 3 of this report.

- U.S. Department of Commerce (USDOC), Bureau of the Census, 1977 Census of Transportation, Commodity Transportation Survey (CTS). The most recent compilation of detailed information on quantities of chemical commodities shipped in the United States is the 1977 Census of Transportation, Commodity Transportation Survey (USDOC 1981a,b,c). Commodity shipping data are compiled in the CTS according to the Commodity Classification for Transportation

Statistics (TCC) codes. This numerical system of coding corresponds closely to that of another key system, the Standard Transportation Commodity Code (STCC) (STCC 1972). Because of the similarities of the TCC and the STCC coding systems, the CTS data can be used to predict the fraction of the total quantity of a manufactured chemical that is shipped by each major mode of transportation, and also to identify the average shipping distance by each mode of transportation.

The age of the data available from the 1977 Census of Transportation is a major source of uncertainty when calculating estimated quantities released. It is possible that commodity shipping patterns presented in the 1977 CTS have changed substantially over the last ten years. A 1982 Commodity Transportation Survey intended to update the 1977 CTS was determined to be unreliable by the Bureau of the Census. Nevertheless, the unofficial statistics developed from this 1982 transportation census can be obtained from the Bureau of the Census, Transportation Census Branch, (301) 763-4363. Note: these data are not to be cited in any published reports and were not used in these methods.

- U.S. International Trade Commission (USITC) annually publishes Synthetic Organic Chemicals, United States Production and Sales. This is the preferred source of information for locating annual production and sales data for specific chemicals. Data are reported by producers only for those items that exceed minimum production volumes or annual sales. Chemicals are grouped by categories, e.g., cyclic intermediates, organic pigments, plasticizers. These groups are assigned section numbers so that a specific chemical can be located by referring to the "Alphabetical Chemical Index" in the appendix of each publication.

- Stanford Research Institute Directory of Chemical Producers-United States (see SRI 1987). This compendium of information on manufacturers of chemicals is a current source of annual production capacity data for a limited number of specific chemicals. The PRODUCTS section of this report is an alphabetical listing of chemicals and end uses of chemicals that is linked to information on the manufacturers and their locations (SRI 1987). Only chemicals produced in commercial quantities (annual production of 5,000 pounds or $5,000 value) are listed. The annual production capacity data obtained from this source can be used in these methods as an upper limit of the quantity of the chemical that could be distributed in commerce.

- U.S. Department of Transportation, Research and Special Programs Administration, Hazardous Materials Data Base (HAZMAT). A primary source used in this study for estimating predictive release factors based on the DOT hazard class of a chemical was the DOT's HAZMAT Data Base, a primary data base of The Hazardous Materials Incident Reporting Subsystem (HMIS). This data base is maintained on the DOT's Digital Electronic Corporation DEC10 computer in Cambridge, Massachusetts. As of 1986, HAZMAT contained 151,067 records documenting inadvertent releases of hazardous materials. The data in HAZMAT are provided by carriers on the Hazardous Materials Incident Report (form DOT F 5800.1) whenever there is an unintentional hazardous materials release during interstate commerce. The types of data contained in HAZMAT are listed in Appendix B, Table B-1.

- U.S. Department of Transportation, Associate Administration for Motor Carriers, Motor Carrier Information Division. This division maintains a data base on highway vehicle accidents only. It is derived from accident reports to the Federal Highway Administration. Currently, computer tapes on the accident data base are available for the period of 1980-1985 and can be purchased. Additional information can be obtained by telephoning the DOT Motor Carrier Information Division at (202) 366-2971.

  Note that a similar type of information on railroads is available through the Systems Support Division (202) 366-2760.

- U.S. Department of Commerce, Interstate Commerce Commission (ICC), Waybill Statistics for Railroad Transportation Information. The ICC waybill data base is an important source of information on the volumes and distances that specific STCC-coded commodities are shipped by rail. While the data are updated annually, there are restrictions on their use, since parts of the data are confidential. Nonconfidential data can be purchased through ALK Associates in New Jersey (609) 683-0220. Government agencies may access the data at no charge by contacting Mr. Jim Nash at the ICC (202) 275-6864.

- Sources of information on waterborne traffic accidents. A current limitation in calculating the total expected quantity of a chemical released from transportation accidents is the lack of specific accident statistics on waterborne transportation. The critical data that are missing include the accident rate (number of accidents per mile) of chemical shipments and the probability of a release given an accident. The U.S. Department of Transportation, U.S. Coast Guard, Office of Marine Safety, maintains two data bases on transportation accidents that could provide some of this information in the future. These data bases are as follows:

  - Marine Investigation Division, Marine Casualty Data Base. This division of the Office of Marine Safety compiles general data on waterborne traffic in the U.S. Although no specific statistics have yet been compiled on hazardous chemical cargo and its relationship to barge or other waterborne traffic accidents, such data may be developed in the future. For current information on the Marine Casualty Data Base, contact LCDR Tom Purtell at (202) 267-1430.

  - Marine Pollution Data Base. Data on pollution incidents involving releases of chemicals or oil to water are stored in the data base maintained by the Office of Marine Safety. Although not directly applicable to the calculation of expected quantity released, this data base may be useful in conducting a fate analysis of a chemical accidentally released to waters of the U.S. Contact Ms. Mary Robey (202) 267-0455.

- The Office of Technology Assessment (OTA), in 1986, published the report, Transportation of Hazardous Materials. The OTA report presents results of a study of federal and state regulation of the transport of radioactive materials, munitions, commodities (manufactured chemicals), and hazardous wastes. An overview of hazardous materials shipping patterns, which was contained in the OTA report, is cited in Section 2 of this report.

2. PATTERNS OF COMMERCIAL DISTRIBUTION OF MANUFACTURED CHEMICALS

This section of the report discusses general patterns of chemicals transportation in the United States. Many of the manufactured chemicals that are distributed in commerce exhibit dangerous properties, such as flammability, reactivity, or acute toxicity, which require special packaging and handling during loading, unloading, and in transit. Manufactured chemicals with dangerous properties are regulated as hazardous materials (or hazardous substances) by DOT and by EPA. The following discussion summarizes available data on the transportation of manufactured chemicals in the United States for major modes of transportation excluding pipelines.

2.1 Distribution of Manufactured Chemicals by Transportation Mode

Four modes of transportation are used to carry most manufactured chemicals in the United States: (1) truck, (2) rail, (3) water, and (4) air. Table 1 presents estimates of the tons of manufactured chemicals transported by each of these modes (USDOC 1981a). The table shows that rail and truck transport were the modes of transportation by which the largest total quantities of manufactured chemicals were shipped in 1977. Waterborne transport ranks third in quantities shipped and ton-miles accumulated, and air transport was the least used mode of transportation for manufactured chemicals. Patterns of transport by each of these modes of transportation are discussed below.

2.1.1 Transportation of Manufactured Chemicals by Rail

In 1977, railroads hauled 65.9 million tons of manufactured chemicals. Rail shipments of manufactured chemicals are usually made by tank car. When ranked by tonnage, rail transportation accounts for 33.4 percent of all industrial inorganic and organic chemicals shipped. Some chemicals are also carried by hopper cars and intermodal flat cars i.e., flat cars carrying intermodal tanks (OTA 1986). In 1977, the average distance of a rail shipment of manufactured chemicals was approximately 500 miles (USDOC 1981a).

2.1.2 Transportation of Manufactured Chemicals by Truck

As shown in Table 1, truck transport was the mode carrying the greatest tonnage of manufactured chemicals in 1977, although trucks ranked second after rail transport in total ton-miles shipped. According to the USDOC Bureau of Census 1977 Commodity Transportation Survey (CTS), trucks transported 77 million tons of chemicals in 1977, with an average shipping distance of 175 miles (USDOC 1981a,b,c).

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Table 1. Estimated Transportation of Industrial Inorganic and Organic Chemicals by Mode in 1977

Mode	Tons transported (thousands)	Percent of total[a]	Ton-miles (million)	Percent of total[a]
Rail	65,930	33.4	32,834	57.5
Truck	77,038	39.0	14,252	25.0
Water	15,386	7.8	8,546	15.0
Air	12	0.006	9	0.02
Other	38,985	19.8	1,464	2.5
Total	197,351	100	57,105	100

[a] Totals may not equal 100 because of rounding.

Source: USDOC (1981a).

2.1.3 Transportation of Manufactured Chemicals by Waterborne Vessels

Waterborne vessels rank third in ton-miles and third in tonnage of manufactured chemicals shipped in 1977. In 1977, an average shipping distance for manufactured chemicals was approximately 550 miles (USDOC 1981a, OTA 1986). In its evaluation of hazardous materials shipments by water, OTA (1986) noted a trend toward declining numbers of bulk shipments of some chemicals classified as hazardous materials. The total tonnage of waterborne shipments of chemicals dropped 13 percent between 1977 and 1982 (OTA 1986).

2.1.4 Transportation of Manufactured Chemicals by Air

According to the CTS (USDOC 1981a), only 12,000 tons of manufactured chemicals were transported by air in 1977. This accounted for less than 1 percent (0.006 percent) of the total tonnage shipped in 1977.

Although quantities of manufactured chemicals carried by air are small, the distances shipped may be large. Manufactured chemicals including cosmetics, pharmaceuticals, and agricultural chemicals account for 80 percent of hazardous materials shipped by air in 1977 (OTA 1986).

2.2 Factors Contributing to Transportation Releases

OTA (1986) reviewed the causes of transportation-related failures reported to the DOT Hazardous Materials Information System (HMIS) between 1976 and 1984. These data, summarized in Table 2, indicate the number of times each type of failure was reported for various modes of transportation.

Although the frequent causes of failures cited in Table 2 vary by mode of transportation, it can be seen that external punctures and loose and defective fittings were frequent causes of releases reported to the HMIS in the eight-year period studied. From the data, OTA concluded that such failures are typical of loading and unloading operations or of cargo shifts during transport (OTA 1986). It should be noted, however, that not all the failure codes are mutually exclusive. For example, OTA could not determine with certainty whether an external puncture occurred because of a vehicle accident or because other cargo shifted/fell during loading and unloading.

Table 2. Cause of Failure by Mode, 1976-84

Number	Code	Air	Highway (for hire)	Highway (private)	Rail	Water	Freight forwarder	Other	Total
1	Dropped in handling	239[a]	4,334	95	30	16	18	11	4,743
2	External puncture	81	12,051[a]	362	481	39[a]	56[a]	35[a]	13,105[a]
3	Damaged by other freight	62	8,192[a]	53	146	8	30[a]	7	8,498
4	Water damage	2	62	2	16	2	--	--	84
5	Damage from other liquid	2	69	1	5	--	--	--	77
6	Freezing	--	182	21	12	1	2	--	218
7	External heat	3	116	17	53	3	1	1	194
8	Internal pressure	57	666	113	399	19	1	4	1,259
9	Corrosion or rust	6	641	36	118	4	1	2	808
10	Defective fittings	60	3,375	321	2,883[a]	27[a]	2	18	6,686
11	Loose fittings	257[a]	7,851	421	3,684[a]	22	18	29[a]	12,282[a]
12	Failure inner receptacle	35	622	17	60	--	--	1	735
13	Bottom failure	24	3,780	66	76	4	7	3	3,960
14	Body/side failure	64	2,517	105	279	14	18	9	3,006
15	Weld failure	4	728	50	70	13	3	4	872
16	Chime failure	2	556	12	35	1	2	2	610
17	Other conditions	129	2,492	282	328	22	5	20	3,278
18	Hose burst	--	872	83	7	1	--	3	966
19	Load/unload spill	2	5,985	1,283[a]	72	2	--	9	7,353
20	Cargo shifted/fell	30	6,127	120	357	14	22	7	6,677
21	Improper loading	18	2,381	15	62	5	10	1	2,492
22	Vehicle accident	3	2,145	972[a]	994	3	1	12	4,130
23	Venting	--	13	25	120	--	--	1	159
24	Release of fumes	3	46	9	147	--	--	2	207
25	Friction	1	101	8	17	2	2	--	131
26	Static electricity	--	8	--	2	--	--	--	10
27	Metal fatigue	--	531	4	12	1	1	--	549

[a] Top two causes of failure in each mode.

Source: OTA 1986.

A recent statistical analysis of selected failure codes reported in the HAZMAT data from 1975 to 1986 indicates that more releasing incidents occur at terminals than during accidents en route, but that the average quantity released per incident is greater for vehicular accidents than at terminal points. For rail, truck, and waterborne transport the number of releases from "loading-unloading," "dropped in handling," or "hose burst" were three to four times greater than the number of releases from "vehicle accident." The mean quantity released from incidents in the last category was an order of magnitude greater than any of the first three categories, which are related to handling at terminal points (Versar 1987).

Previous studies have shown that the probability of a hazardous materials transportation release is somewhat related to traffic density and physical obstructions. French and Richards (1973) found that the highest percentage of barge casualties on the West Gulf Intracoastal Waterway occurred at locations with dense traffic or obstructions such as bridges or pilings. Similarly, ICF (1984) analyzed 1980-1982 truck accident and volume data from Texas, California, New Jersey, and Massachusetts. Combining the state analyses with an analysis of DOT's HAZMAT data base, ICF estimated that the truck accident rate (for accidents in which there is a release of hazardous materials) is highest in urban areas (7.3×10^{-7} releasing accidents per mile), lower on U.S. or state highways (4.5×10^{-7} releasing accidents per mile), and lowest on U.S. interstates (1.3×10^{-7} releasing accidents per mile) (ICF 1984). Another analysis of 1980, 1981, and January, February, and March 1984 data from the HAZMAT data base, combined with en route vehicular accident rates and collision data provided by DOT's Bureau of Motor Carrier Safety, confirmed this range of releasing accidents for tank trucks. It was calculated that, on the average, tank trucks are involved in 3.5×10^{-7} releasing accidents per mile (USEPA 1985).

3. METHOD OF CALCULATING THE EXPECTED QUANTITY RELEASED OF COMMERCIALLY AVAILABLE CHEMICALS

The amount of a chemical expected to be released because of transportation accidents can be calculated using several types of information about shipment of the chemical. The information includes: (1) the quantities that will be shipped, (2) the mode(s) of shipment, and (3) historical accident data. Engineering judgment is required when such data are incomplete, which is often the case. Section 3.1 describes a general method of calculating the expected quantity of a chemical released annually because of en route transportation accidents. Section 3.2 presents examples of how to use available data to calculate the expected quantity released annually of three commercially available chemicals: ethylene oxide, di-(2-ethylhexyl) phthalate (DEHP), and formaldehyde.

Although the method involves assembling and manipulating data from a number of different sources, the technical approach can be summarized as follows:

- Characterize the chemical in question according to commodity type and other key identifying parameters (Step 1);
- Estimate the quantities of the chemical that are shipped annually by each major mode of transportation (Steps 2, 3, and 4);
- Determine the average quantity per shipment and the average shipment distance by each mode of transportation (Steps 5 and 6); and
- Using transportation accident statistics, calculate the expected annual number of releases and the fraction of the total annual shipments that would be released en route (Steps 8, 9, 10, and 11).

With this information, the expected quantities of chemical released annually by each mode of transportation can be calculated (Step 12) and those quantities summed to yield the expected total quantity of chemical released annually (Step 13). Each of these steps is discussed in detail in the next section.

3.1 The General Method

In order to make release calculations as straightforward as possible, a sample worksheet has been provided as Figure 1. The organization of the worksheet parallels the steps of the following general method of predicting release frequencies and quantities for a given chemical. When

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Step No.	Item/Parameter	Abbreviation	Values of Parameters				Units	Reference/Comment
			Truck	Rail	Waterborne	Air		
1.	Identify:							
	Chemical name.							
	DOT hazard class.							49 CFR 172.101 (USDOT 1986b)
	Standard Transportation Commodity Code (STCC).							STCC 1972; National Motor Freight Classification Board Table 3
	Physical state.							
	CAS registry number.							CRC 1986, USEPA 1986
2.	Total annual quantity shipped.						pounds	Options: USITC, SRI, Chemical Producers' Data Base, or ICC (pounds shipped annually/2,200)
	Convert to metric tons.	(S)					kkg	
3.	Fraction shipped by each mode of transportation.[a]	(F)						Calculated using data from USDOC 1981a, or from ICC waybill data for rail only
4.	Total quantity shipped annually by each mode of transportation.	(W)					kkg	W = S x F
5.	Average quantity per shipment.	(V)					kkg	Genereaux et al. 1984, ICC waybill data for rail only, or USDOT 1986a Table 4
6.	Average shipment distance for each mode of transportation.	(M)					Miles per shipment	Appendix C; or use ICC waybill data for rail only
7.	Annual number of shipments.	(Y)					Shipments per year	$Y = \frac{W}{V}$
8.	Accident rate for each mode of transportation.	(A)	1.2×10^{-6}	6.0×10^{-6}	[b]	5.0×10^{-9}	Accident/mile	USEPA 1985, USDOT 1986a, USDOT 1987

Figure 1. Sample worksheet for predicting the amount of chemical released because of transportation accidents.

Step No.	Item/Parameter	Abbreviation	Values of Parameters: Truck	Values of Parameters: Rail	Values of Parameters: Waterborne	Values of Parameters: Air	Units	Reference/Comment
9.	Probability of a release, given an accident, for each mode of transportation.	(P)	______	______	b ______	______	Release per accident	P-values for the following: Tanker truck 0.29 Truck (steel drum containers, etc.) 0.26 Rail 0.130 Air 1.0
10.	Annual number of releases.	(N)	______	______	______	______	Releases/ year	N = M x Y x A x P
11.	Fraction of container contents released.[a]	(R)	______	______	______	______		Options: Tables 6, 7, and 8[c]
12.	Quantity of chemical released annually by each mode of transportation.	(Q)	______	______	______	______	kkg	Q = V x N x R
13.	Total quantity of chemical released annually.	(Q_{Total})	Q_{Truck}	______				
			+ Q_{Rail}	______				
			+ $Q_{Waterborne}$	______				
			+ Q_{Air}	______				
				______	= Total quantity released.		kkg	

---

[a] Dimensionless factor.

[b] Barge data are not currently available; see Section 3.1 for possible future sources of this information.

[c] Table 6 is used when mode of transportaton is known but physical state and DOT hazard class are unknown. Table 7 is used when mode of transportation and physical state are known but DOT hazard class is unknown. Table 8 is used when mode of transportation, physical state, and DOT hazard class are all known.

Figure 1. (continued)

applying the method to a specific chemical, one should record information on values obtained for the required parameters on a copy of the sample worksheet.

For some of the steps, there are optional sources of information. In particular, the availability of Interstate Commerce Commission (ICC) waybill data on railroad shipments allows for several "shortcuts" in calculating releases by rail only. These options are noted where applicable.

Note also that the information required to calculate releases during waterborne transportation is incomplete at present. However, because potential sources of needed information (e.g., accident statistics) may become available in the near future, these sources are described in this method, and spaces for calculating waterborne transportation releases are included in the worksheet.

Step 1. Provide information that characterizes the chemical in question. The information obtained in this step (DOT hazard class, physical state, STCC code, CAS registry number, and quantity shipped) is used in subsequent steps to determine the average annual release of a chemical because of transportation-related accidents. To obtain the necessary information, the following actions should be taken:

- For a given chemical, determine its DOT hazard class. Classes of DOT regulated chemicals are listed in 49 CFR 172.101 (USDOT 1986b). Descriptions of each class are also presented in Appendix A of this report, and examples are included in the sample calculations in Section 3.2 (note that the identification of the DOT hazard class is helpful but not essential to completing the calculations described in this method).

- If the chemical in question is a newly manufactured chemical (e.g., a PMN chemical), then an appropriate DOT hazard class may be assigned by using the definitions in Appendix A.

- Ascertain the Standard Transportation Commodity Code (STCC) of the chemical. STCC codes are derived from the Standard Transportation Commodity Code Tariff, No. 1-A (STCC 1972). A complete listing of STCC codes can be purchased from the Western Truck Line Company, 222 South Riverside Plaza, Chicago, Illinois 60606. The telephone number is (312) 648-7849. Individual STCC codes may be obtained by contacting Mr. Gordon Anderson at the National Motor Freight Classification Board (703) 838-1811.

- Determine the physical state of the chemical (i.e., whether the chemical is a solid, liquid, or gas at the standard conditions of 25°C and 1 atmosphere pressure). Sources of information that may be helpful in determining a chemical's physical state are listed in Table 3. Note that although compressed gases are transported as liquids, they are considered gases for the purpose of this method because they volatilize readily upon release from a shipping container.

- Determine the CAS registry number of the chemical. CAS registry numbers can be found in the CRC Handbook of Data on Organic Compounds (CRC 1985) or in the USEPA TSCA Inventory (USEPA 1986). Online computerized data bases that can be accessed for CAS registry numbers include the National Library of Medicine's Chemline and the Chemical Abstracts Registry File, which is part of the DIALOG online system.

Step 2. Estimate the annual quantity shipped using one of the following options. Option 1 is preferred. Option 4 can be used only if ICC information is available on rail transport.

Option 1: The U.S. International Trade Commission publication, Synthetic Organic Chemicals--United States Production and Sales, can be used to find the amount of the chemical sold; this amount is then assumed to be the quantity shipped. The limitation in using this source is that sales information is often presented for categories of chemicals rather than for individual chemicals. An advantage of this data source is that it is updated annually; see USITC 1986 in the reference section.

Option 2: The annual quantity shipped can be estimated using data on production capacity in the Stanford Research Institute Directory of Chemical Producers--United States. This publication is updated annually; see SRI 1987 in the reference section. If SRI data are used, it should be taken into consideration that actual production is seldom greater than 80 percent of production capacity.

Table 3. Sources of Information Useful in Determining a Chemical's Physical State at Standard Conditions of Temperature and Pressure

Title	Comment
Chemical Engineer's Handbook, 6th ed. (1984)	See Section 3 of handbook.
CRC Handbook of Data on Organic Compounds, Vols. I and II (1985)	See alphabetical listing of chemicals.
CRC Handbook of Physics and Chemistry, 6th ed. (1986)	See Sections C-42 through C-553.
Handbook of Toxic and Hazardous Chemicals and Carcinogens (1985)	See alphabetical listing of chemicals.
The Merck Index (1983)	See alphabetical listing of chemicals.

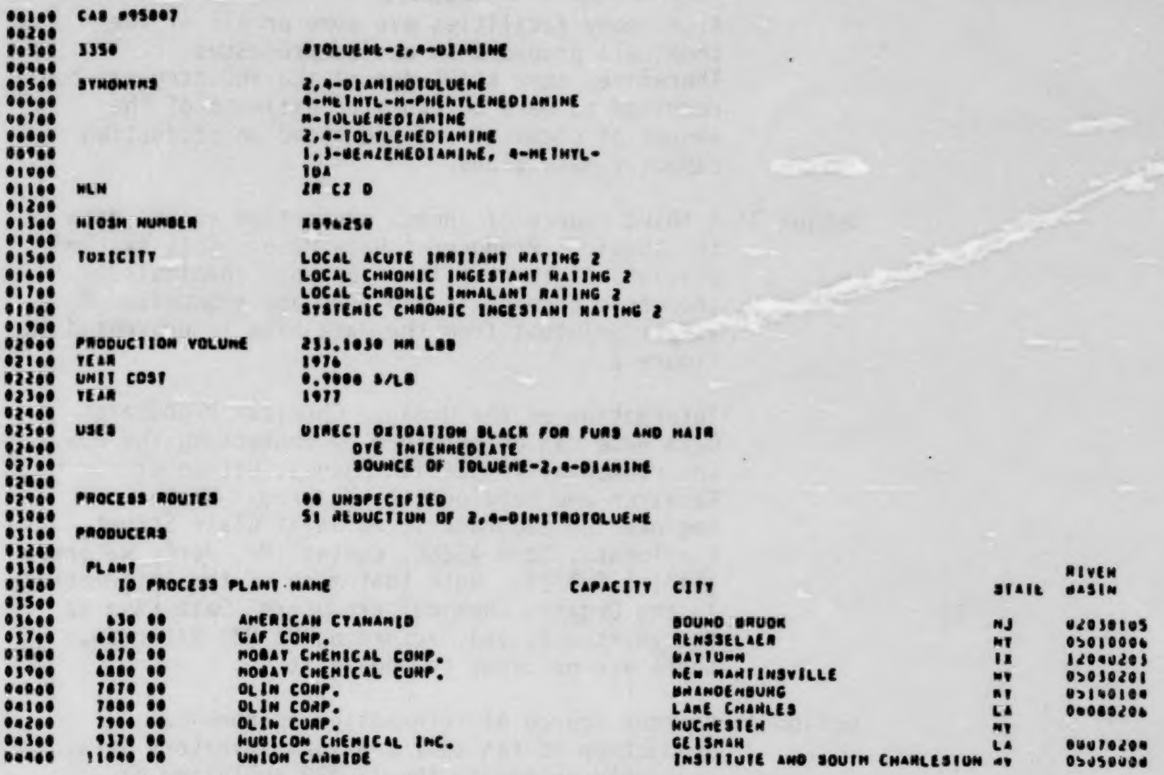
Also, many facilities use some or all of the chemicals produced in onsite processes. Therefore, some knowledge of the industry may be required to make an educated estimate of the amount of chemical shipped based on production capacity data alone.

Option 3: A third source of annual production volume data is the Chemical Producers' Data Base. This system consists of three files: organic chemicals, inorganic chemicals, and dyes and pigments. A sample printout from the data base is presented in Figure 2.

Information on the Organic Chemical Producers' Data Base can be obtained by contacting the U.S. Environmental Protection Agency, Office of Research and Development, Hazardous Waste Engineering Laboratory, 26 Saint Clair Street, Cincinnati, Ohio 45268; contact Mr. Jerry Waterman (513) 569-7214. Note that much of the information in the Organic Chemical Producers' Data Base is ten years old, and, according to Mr. Waterman, there are no plans to update it.

Option 4: Another source of information on chemical production is the 1977 EPA TSCA inventory data, available online as the TSCAPP subsystem of Chemical Information Systems (CIS). Nonconfidential business data included in TSCAPP are: (1) names of reported chemicals, (2) production volume range, and (3) manufacturing plant location. CIS plans to supplement TSCAPP with information from the EPA 1986-87 update of the TSCA Inventory. If these chemical production data are used, some knowledge of the particular industry may be needed to estimate the quantity shipped versus the quantity used onsite.

Codes for production volume range in TSCAPP are as follows:



```
00100  CAS #95807
00200
00300  3350                  *TOLUENE-2,4-DIAMINE
00400
00500  SYNONYMS              2,4-DIAMINOTOLUENE
00600                        4-METHYL-M-PHENYLENEDIAMINE
00700                        M-TOLUENEDIAMINE
00800                        2,4-TOLYLENEDIAMINE
00900                        1,3-BENZENEDIAMINE, 4-METHYL-
01000                        TDA
01100  WLN                   ZR CZ D
01200
01300  NIOSH NUMBER          XS96250
01400
01500  TOXICITY              LOCAL ACUTE IRRITANT RATING 2
01600                        LOCAL CHRONIC INGESTANT RATING 2
01700                        LOCAL CHRONIC INHALANT RATING 2
01800                        SYSTEMIC CHRONIC INGESTANT RATING 2
01900
02000  PRODUCTION VOLUME     233.1030 MM LBS
02100  YEAR                  1976
02200  UNIT COST             0.9000 $/LB
02300  YEAR                  1977
02400
02500  USES                  DIRECT OXIDATION BLACK FOR FURS AND HAIR
02600                             DYE INTERMEDIATE
02700                             SOURCE OF TOLUENE-2,4-DIAMINE
02800
02900  PROCESS ROUTES        00 UNSPECIFIED
03000                        51 REDUCTION OF 2,4-DINITROTOLUENE
03100  PRODUCERS
03200
03300   PLANT                                                                          RIVER
03400     ID PROCESS PLANT NAME                      CAPACITY  CITY                    STATE  BASIN
03500
03600     630 00        AMERICAN CYANAMID                      BOUND BROOK                NJ  02030105
03700    6410 00        GAF CORP.                              RENSSELAER                 NY  05010006
03800    6870 00        MOBAY CHEMICAL CORP.                   BAYTOWN                    TX  12040203
03900    6880 00        MOBAY CHEMICAL CORP.                   NEW MARTINSVILLE           WV  05030201
04000    7870 00        OLIN CORP.                             BRANDENBURG                KY  05140104
04100    7880 00        OLIN CORP.                             LAKE CHARLES               LA  08080206
04200    7900 00        OLIN CORP.                             ROCHESTER                  NY
04300    9370 00        RUBICON CHEMICAL INC.                  GEISMAR                    LA  08070204
04400   11040 00        UNION CARBIDE                          INSTITUTE AND SOUTH CHARLESTON WV  05050008
```

Figure 2. Sample retrieval from the Organic Chemical Producers' Data Base by CAS registry number.

Code	Volume
0	Less than 1,000 lb
1	1,000 to 10,000 lb
2	10,000 to 100,000 lb
3	100,000 to 1,000,000 lb
4	1,000,000 to 10,000,000 lb
5	10,000,000 to 50,000,000 lb
6	50,000,000 to 100,000,000 lb
7	100,000,000 to 500,000,000 lb
U	No Report

To obtain additional information on accessing TSCAPP, one should contact:

Ms. Laurie Donaldson
Chemical Information Systems, Inc.
7215 York Road
Baltimore, MD 21212
1-(800) 247-8737 or
(301) 321-8440

Option 5: FOR RAIL ONLY: The Interstate Commerce Commission (ICC) maintains a waybill file of annual quantities of all commodities shipped by rail. Shipping information on individual commodities can be searched in this file by STCC code (see Step 1). USEPA or other government agency personnel can obtain current waybill data on a specific chemical by contacting Mr. Jim Nash of the ICC at (202) 275-6864.

Because the ICC waybill data are based on 1 percent (or 6 percent for 1986 or later) of the actual quantities shipped, multiply the value given for quantity shipped in the waybill file by the appropriate factor (100 for 1 percent waybill data, 16.7 for 6 percent waybill data) in order to estimate the actual quantity shipped by rail. Then, because the ICC quantities are reported in tons, divide by 1.1 to convert to kkg.

If ICC data are used and only rail transport is being considered, enter the value calculated from waybill data for quantity shipped (in kkg) on the line marked "S" on the worksheet, and then skip to Step 4, Option 2.

If the annual quantity shipped cannot be estimated using any of these options, it may be helpful to contact trade associations or professional organizations for shipping information on a specific chemical. Potential contacts for this information are listed in Table 4.

Enter the value obtained for annual quantity shipped on the worksheet (Step 2). Convert this value to metric tons (kkg), and enter the corrected value on the line designated by "S" on the worksheet.

Step 3. Calculate the fraction of the total annual quantity of chemical shipped that is transported by each mode of transportation. This calculation requires data from the Bureau of the Census Commodity Transportation Survey Summary (CTS Summary) for 1977 (USDOC 1981a). Commodities included in the CTS Summary are classified using the Commodity Classification for Transportation Statistics (TCC) codes. The system of numbering within the TCC codes closely parallels that of the STCC codes (see Step 1). Therefore, for the purposes of this method, the data on commodity shipments in the CTS Summary are searched by matching the STCC code, obtained for the specific chemical in Step 1, with the most closely related TCC code listed in Table 2 of the CTS Summary. It is assumed that the fraction of the STCC (or TCC) commodity group that is shipped by each mode of transportation is representative of the shipping pattern for each chemical within that commodity group. For calculating the fraction that is shipped, the following procedures are used:

(a) Using the STCC code of the chemical (from Step 1), find the values for tons shipped in the CTS Summary, Table 2, Column B. The total quantity of the TCC commodity group shipped by all modes of transportation is listed first, followed by values for tons shipped by different modes of transportation: rail, motor carrier (ICC and non-ICC), private truck, air, water, parcel delivery, and other and nknown. For truck transport, sum the values for tons shipped for motor carriers (total of ICC and non-ICC), and private truck categories.

(b) Calculate the fraction of the STCC commodity group that is shipped by each mode of transportation by dividing the value for quantity shipped by each mode by the corresponding value for total quantity shipped.

Table 4. Associations That May Provide Production Volume Data for Chemicals

Association	Address	Telephone number
American Chemical Society	1155 16th St. NW Washington, DC 20036	202-872-4600
Chemical Marketing Research Association	139 Chestnut Ave. Staten Island, NY 10305	212-727-0550
Chemical Specialties Manufacturers Association	1001 Connecticut Ave. NW Washington, DC 20031	202-872-8100
National Association of Chemical Distributors	1110 Vermont Ave. NW, Suite 1150 Washington, DC 20005	202-296-9200
Synthetic Organic Chemical Manufacturers Association	1075 Central Park Ave. Scarsdale, NY 10583	914-725-1492

(c) Enter the calculated values for fraction shipped by each mode of transportation on the worksheet on the line designated by "F."

Alternative approach: Use this method if truck and rail are the primary modes of transport and ICC (rail) data are available to a level of STCC detail greater than the CTS data. In this case, subtract the ICC (rail) quantity from the total annual quantity shipped (Line 5) to estimate the quantity transported by truck. For example, this approach can be helpful if ICC data are available for STCC 2818144 but CTS data are available only for STCC 2818.

Step 4. Estimate the quantities shipped annually for each mode of transportation.

Option 1: This option makes use of information developed in Steps 2 and 3. Multiply the total estimated quantity shipped (parameter "S" from Step 2) by the fraction shipped by each mode of transportation (parameter "F" from Step 3). Enter the results on the line identified by "W" on the worksheet.

Option 2: FOR RAIL ONLY: If estimating for rail, one can use the ICC waybill data. The total quantity shipped by rail can be obtained directly, as described in Step 2, Option 4.

Enter the value for quantity shipped by rail (in kkg) on the worksheet on the line marked "W."

Step 5. Estimate average quantity per shipment for each mode of transportation.

Option 1: Information on standard volumes of liquids or compressed gases shipped by tank truck or rail is available in a recent article by Genereaux et al., "Transportation and Storage of Fluids," in Perry's Chemical Engineers Handbook, 1984. The following standard volumes can be used to estimate the average quantity per shipment for tank trucks and rail:

- Tank trucks: 5,000 to 7,000 gallons (Genereaux et al. 1984); and

- Rail cars: approximately 20,000 gallons of liquid chemicals, or 30,000 to 33,000 gallons of liquified compressed gases (e.g., propane, vinyl chloride, or butadiene) (Genereaux et al. 1984).

The quantity per shipment of all modes of transportation can be estimated in two steps: (1) determine the TCC code that best describes the chemical in question, and (2) locate the median value for quantity shipped in Table 4 of the CTS (USDOC 1981a) of the specific mode of transportation. Use this quantity as the average shipment size.

Additional information on specifications of containers used to carry hazardous materials can be found in DOT regulations, 49 CFR 173 and 178. Part 173 of the regulation deals with container and packaging requirements for specific hazard classes of chemicals (USDOT 1986c). Part 178 describes specifications of various types of containers: metal barrels, drums, and kegs (USDOT 1986d); portable tanks (USDOT 1985); and containers for motor vehicles (USDOT 1986e).

Container volume data must be converted to kkg before a value is entered on the worksheet. This is done by multiplying the volume of the container by the density of the solid, liquid, or liquified compressed gas and appropriate conversion factors (e.g., kg/L x 3.785 L/gal x 0.001 kkg/kg). Densities of specific chemicals can be found in the CRC Handbook of Chemistry and Physics (CRC 1986).

Option 2: FOR RAIL ONLY: If estimating rail releases, one can use the ICC waybill data as a source of the average quantity per shipment (i.e., rail car). These data are organized by STCC code (Step 1). The average quantity shipped per rail car is given in tons, which should be converted to kkg by dividing by 1.1.

Enter the value (in kkg) for average quantity per shipment for each mode of transportation on the line marked "V" on the worksheet.

Step 6. Estimate the average distance that the chemical is transported by each mode of transportation.

Option 1: Information in the 1977 Commodity Transportation Survey Summary (USDOC 1981a) can be used with one of the methods found in Appendix C to estimate the average distance a chemical is shipped. The method of choice depends on the availability of information on the quantity, origin, and destination of shipments from manufacturing facilities as follows:

Method	Average quantity/ shipment	Origin of shipments	Destination of shipments
C-1	Unknown	Unknown	Unknown
C-2	Unknown	Known	Unknown
C-3	Known	Unknown	Unknown

Option 2: FOR RAIL ONLY: When rail releases are estimated, the average shipment distance can be obtained from the ICC waybill data. This can be calculated by dividing the total car miles by the number of cars. An example of this calculation is presented in Section 3.2.2, Part (2), Step 6 of this report.

Enter the values for average distance shipped by each mode of transportation on the line designated by "M" on the worksheet.

Step 7. Estimate the annual number of shipments.

Option 1: Calculate the annual number of shipments by each mode of transportation using data obtained in Steps 4 and 6. The annual number of shipments (designated here by "Y") is equal to the quantity shipped annually (W) divided by the average quantity per shipment (V):

$$Y = W/V = (\text{quantity shipped annually})/(\text{quantity per shipment}).$$

Option 2: FOR RAIL ONLY: If estimates are for rail, the number of shipments per year can be taken directly from ICC waybill data. Because the data are based on a 1 or 6 percent sample, multiply the number of cars by 100 (1 percent sample) or 16.7 (6 percent sample) to get the actual number of shipments.

Enter the value for annual number of shipments for each mode of transportation on line "Y" of the worksheet.

Step 8. Select the average accident rate for each mode of transportation. In this step, statistics for the number of accidents per mile are factored into the release calculation. The factor varies by mode of transportation. The values for truck and rail transportation accident rates have been entered on line "A" of the sample worksheet (Figure 1). These values are as follows:

Truck: 1.2×10^{-6} accidents/mile (USEPA 1985);
Rail: 6.0×10^{-6} accidents/mile (USDOT 1986a); and
Air: 5.0×10^{-9} accidents/mile (USDOT 1987).*

Accident rates for barges and other forms of waterborne transportation are not available at present. To obtain information regarding the development of a data base that can provide this information in the near future, contact Mr. Theo Moniz, USDOT, U.S. Coast Guard Office of Marine Safety, Marine Investigation Division, (202) 267-1430.

Step 9. Select the appropriate probability of a release given an accident for each mode of transportation. The values available for this parameter vary with the mode of transportation, and, for trucks, with the type of container. Probability of a release (P), given an accident, is as follows:

Truck:	For tank trucks, P is 0.29 releases/accident (USEPA 1985). For trucks transporting containers, i.e., other than tank trucks, P is 0.26, with the estimate based on data from ICF (1984).
Rail:	The probability of a release, given an accident involving rail transport, is 0.130 (USDOT 1986a).
Air:	Because the aircraft accident rate is based on accidents that involve fatalities, it is assumed that every accident is severe enough to damage containers and release chemicals. Under these conditions, the probability of a release, given an accident, is 1.

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* This accident rate was developed from statistics in USDOT (1987) for the number of fatal accidents per million miles.

Waterborne: Presently, data are not available for estimating probable release factors for accidents during water transport in the United States. However, other data on incidents involving releases of chemicals to water are stored in the Marine Pollution Data Base, maintained by the U.S. Coast Guard Office of Marine Safety. For more information on this data base, contact Ms. Mary Robey at (202) 267-0455.

Enter the values for probability of release, given an accident, for each of the appropriate modes of transportation on the worksheet on the line designated "P."

Step 10. Calculate the expected annual number of releases for each mode of transportation (N). This value is obtained according to the following equation:

$$N = M \times Y \times A \times P$$

where

M = Average shipment distance (Step 6)
Y = Annual number of shipments (Step 7)
A = Accident rate (accidents/mile, Step 8)
P = Probability of a release, given an accident (Step 9).

Enter the calculated value for the expected number of releases per year for each mode of transportation on line "N" of the worksheet.

Step 11. Estimate the fraction of the container contents released for an accident involving a release. This step incorporates the results of a statistical analysis of the DOT HAZMAT data base on the history of chemical releases during transportation. This analysis is described in detail in Appendix B of this report. If data are not available to determine the types of containers in which a chemical is transported, or if the chemical is carried as part of a larger shipment, then the fraction of shipment released should be obtained from Tables B-7, B-8, and B-14 in Appendix B and used in the calculations. (NOTE: Data in Tables B-7, B-8, and B-14 are presented as percentages (vs. fractions) of container contents released. The data from these tables should be converted before they are used in these calculations.)

The results of the analysis indicate that the fraction of the contents in a shipping container that is expected to be released during a transportation accident will vary depending on the mode of transportation, the physical state of the chemical, and the DOT hazard class (identified in Step 1 of this method).

Table 5 lists the DOT hazard classes and the corresponding physical states and commodity codes used in the statistical analysis. Depending upon the availability of information for the specific chemical in question, mean values for the fraction of container contents released during an accident can be obtained from Tables 6, 7, and 8, as follows:

Mode of transportation	Physical state	DOT hazard class	Table
Known	Unknown	Unknown	6
Known	Known	Unknown	7
Known	Known	Known	8

Because the data in the HAZMAT data base were not normally distributed (see Appendix B), three options are available when choosing a value for fraction of container contents released from Tables 6, 7, and 8:

(1) Select the 90th percentile value for "worst-case" estimates; or

(2) Select the "mean" value for a conservative estimate (because the data are not normally distributed, the use of the "mean" value may cause an overestimation of the quantity of chemicals released); or

(3) Select the "median" value.

For each mode of transportation, enter the value obtained from the tables for fraction of container contents released during an accident on line "R" of the worksheet.

Step 12. Estimate the quantity of chemical released annually for each mode of transportation (Q). This value is calculated according to the following equation:

$$Q = V \times N \times R$$

Table 5. Summary of DOT Hazard Classes

Physical state	Commodity class (code for DOT hazard class)	DOT hazard class
Liquid	2	Other regulated material Class A (ORMA)
	4	Other regulated material Class B (ORMB)
	6	Other regulated material Class C (ORMC)
	8	Other regulated material Class D (ORMD)
	9	Other regulated material Class E (ORME)
	20	Combustible liquid
	25	Flammable liquid
	95	Corrosive material
Solid	10	Organic peroxide
	30	Flammable solid
	35	Oxidizer
	60	Poison, Class B
Gas	45	Nonflammable compressed gas
	50	Flammable compressed gas
	55	Poison, Class A
	65	Irritating material

Note: See Appendix A for definitions of each DOT hazard class.

Table 6. Values for the Fraction of Container Contents Released (To Be Used If the Mode of Transportation Is Known)

Mode of transportation	Number of data records (N)	Mean	Standard deviation	Upper 90% confidence limit	Median	90th Percentile
Air	589	.2867	.3706	.3118	.0700	1.000
Barge	110	.2842	.3702	.3421	.0738	1.000
Rail	6120	.1118	.2847	.1177	.0001	0.510
Truck	45738	.3256	.3925	.3286	.0935	1.000

Source: Statistical analysis of the HAZMAT data base 1986. (See Appendix B for more details.)

Table 7. Values for the Fraction of Container Contents Released (To Be Used If Physical State and Mode of Transportation Are Known)

Physical state	Mode of transportation	Number of data records (N)	Mean	Standard deviation	Upper 90% confidence limit	Median	90th Percentile
Gas	Air	9	.8197	.3689	1.0000	1.0000	1.0000
Gas	Barge	6	.5519	.4981	.8853	.6273	1.0000
Gas	Rail	1043	.0518	.2070	.0623	.0000	.0176
Gas	Truck	622	.4907	.4333	.5192	.4685	1.0000
Liquid	Air	534	.2761	.3620	.3018	.0560	1.0000
Liquid	Barge	83	.2828	.3678	.3490	.0817	1.0000
Liquid	Rail	4608	.1072	.2776	.1139	.0002	.5000
Liquid	Truck	40257	.3239	.3913	.3272	.0909	1.0000
Solid	Air	46	.3059	.3997	.4026	.1125	1.0000
Solid	Barge	21	.2135	.3217	.3287	.0376	.9333
Solid	Rail	469	.2899	.4071	.3207	.0182	1.0000
Solid	Truck	4859	.3179	.3919	.3271	.0909	1.0000

Source: Statistical analyses of the HAZMAT data base 1986. (See Appendix B for more details.)

Table 8. Values for the Fraction of Container Contents Released (To Be Used If Physical State, DOT Hazard Class, and Mode of Transportation Are Known)

Physical state	Commodity class (code for DOT hazard class)[a]	Mode of transportation	Number of data records (N)	Mean	Standard deviation	Upper 90% confidence limit	Median	90th Percentile
Gas	45	Air	3	1.0000	.0000	1.0000	1.0000	1.0000
Gas	45	Barge	4	.5772	.4950	.9831	.6273	1.0000
Gas	45	Rail	431	.0528	.2106	.0694	.0001	.0099
Gas	45	Truck	270	.5651	.4353	.6086	.6667	1.0000
Gas	50	Air	6	.7296	.4341	1.0000	1.0000	1.0000
Gas	50	Barge	1	1.0000	--	--	1.0000	1.0000
Gas	50	Rail	609	.0512	.2052	.0648	.0000	.0196
Gas	50	Truck	309	.4431	.4215	.4824	.3636	1.0000
Gas	55	Rail	3	.0335	.0576	.0880	.0005	.1000
Gas	55	Truck	18	.3681	.4632	.5472	.0744	1.0000
Gas	65	Air	0	--	--	--	--	--
Gas	65	Barge	1	.0022	--	--	.0022	.0022
Gas	65	Truck	25	.3629	.4273	.5030	.0909	1.0000
Liquid	2	Air	37	.4413	.3976	.5484	.5000	1.0000
Liquid	2	Rail	18	.3674	.4493	.5411	.1069	1.0000
Liquid	2	Truck	277	.4726	.4185	.5138	.3636	1.0000
Liquid	4	Air	17	.5996	.4233	.7679	.8000	1.0000
Liquid	4	Rail	3	.0240	.0405	.0624	.0012	.0708
Liquid	4	Truck	32	.1918	.2825	.2737	.0523	.7475
Liquid	6	Rail	2	.4973	.7027	1.0000	.4973	.9941
Liquid	6	Truck	25	.4305	.4012	.5621	.2760	1.0000
Liquid	8	Air	4	.5373	.3500	.8243	.5000	1.0000
Liquid	8	Truck	25	.7634	.3564	.8803	1.0000	1.0000
Liquid	9	Barge	1	.0286	--	--	.0286	.0286
Liquid	9	Rail	21	.2160	.3496	.3811	.0751	1.0000
Liquid	9	Truck	191	.2604	.3673	.3040	.0500	1.0000
Liquid	20	Air	6	.5834	.3816	.8389	.5500	1.0000
Liquid	20	Barge	7	.0591	.1136	.1296	.0015	.3000
Liquid	20	Rail	388	.1179	.2832	.1414	.0002	.6432
Liquid	20	Truck	1995	.2258	.3305	.2379	.0333	.8934

Table 8. (continued)

Physical state	Commodity class (code for DOT hazard class)[a]	Mode of transportation	Number of data records (N)	Mean	Standard deviation	Upper 90% confidence limit	Median	90th Percentile
Liquid	25	Air	377	.1996	.3114	.2259	.0350	.8000
Liquid	25	Barge	43	.2990	.3653	.3904	.0849	1.0000
Liquid	25	Rail	1665	.1274	.2979	.1394	.0002	.6667
Liquid	25	Truck	17494	.2743	.3629	.2788	.0727	1.0000
Liquid	95	Air	93	.4303	.4130	.5006	.2500	1.0000
Liquid	95	Barge	32	.3178	.3995	.4336	.0955	1.0000
Liquid	95	Rail	2511	.0889	.2574	.0973	.0001	.2727
Liquid	95	Truck	20218	.3747	.4121	.3795	.1600	1.0000
Solid	10	Air	1	.1000	--	--	.1000	.1000
Solid	10	Rail	7	.2167	.3662	.4437	.0006	1.0000
Solid	10	Truck	328	.4447	.4110	.4819	.2500	1.0000
Solid	30	Air	4	.5428	.5321	.9791	.5833	1.0000
Solid	30	Barge	3	.0405	.0699	.1067	.0003	.1212
Solid	30	Rail	79	.1431	.3358	.2051	.0001	1.0000
Solid	30	Truck	353	.2166	.3521	.2473	.0227	1.0000
Solid	35	Air	9	.5804	.4517	.8273	.7500	1.0000
Solid	35	Barge	3	.1967	.3247	.5041	.0182	.5714
Solid	35	Rail	207	.3967	.4406	.4469	.1515	1.0000
Solid	35	Truck	1238	.3299	.3958	.3484	.1000	1.0000
Solid	60	Air	32	.2055	.3331	.3021	.0165	1.0000
Solid	60	Barge	15	.2515	.3523	.4007	.0659	1.0000
Solid	60	Rail	176	.2330	.3650	.2782	.0182	1.0000
Solid	60	Truck	2940	.3108	.3889	.3226	.0886	1.0000

[a] Refer to Table 5 for the corresponding DOT hazard class.

Source: Statistical Analysis of the HAZMAT Data Base, 1986. (See Appendix B for more details.)

where

V = Average quantity of each shipment (Step 5)
N = Expected number of releases per year (Step 10)
R = Expected fraction of container contents released in an accident (Step 11).

Enter the product of the calculation for each mode of transportation on the line designated by "Q" on the worksheet.

Step 13. Estimate the total quantity of chemical released annually by all modes of transportation. By summing the values for quantities of chemical released annually by each mode of transportation (Step 12), one can calculate the total expected quantity released.

$$Q_{total} = Q_{truck} + Q_{rail} + Q_{waterborne}$$

Spaces for this calculation are provided in the worksheet under Step 13. This step completes the general method.

3.2 Sample Calculations

In this section of the report, the general method described in Section 3.1 is applied using available information on the transportation of three chemicals, di-(2 ethylhexyl) phthalate (DEHP), ethylene oxide, and formaldehyde. Section 3.2.1 includes calculations of releases of DEHP from tank trucks, railroad tank cars, and air transport. Section 3.2.2 presents an example of the use of ICC waybill data for calculation of releases of ethylene oxide by rail only. In addition, releases of formaldehyde from tank trucks and steel drums are calculated in Section 3.2.3. Each of these calculations is accompanied by a copy of the worksheet (Figure 1) completed using data specific to the chemical and the mode of transportation considered. The technique of predicting releases of the formaldehyde from steel drums is explained without an accompanying worksheet.

3.2.1 Expected Releases of DEHP During Transportation Accidents

The following example demonstrates the use of available information to calculate the expected quantity of di-(2-ethylhexyl)phthalate (DEHP) that would be accidentally released from railroad tank cars, trucks, and air transport over a one-year period. The example is presented in steps corresponding to the general method discussed in Section 3.1. Figure 3 is a sample worksheet that has been completed using data specific to transportation of DEHP by railroad tank cars, tank trucks, and air transport.

Step No.	Item/Parameter	Abbreviation	Values of Parameters				Units	Reference/Comment
			Truck	**Rail**	**Waterborne**	**Air**		
1.	Identify:							
	Chemical name.		Di-(2-ethylhexyl)phthalate (DEHP)					
	DOT hazard class.		Not applicable					49 CFR 172.101 (USDOT 1986b)
	Standard Transportation Commodity Code (STCC).		2899991					STCC 1972; National Motor Freight Classification Board Table 3
	Physical state.		Liquid					
	CAS registry number.		117-81-7					CRC 1986, USEPA 1986
2.	Total annual quantity shipped.		260,245,000				pounds	Options: USITC, SRI, Chemical Producers' Data Base, or ICC
	Convert to metric tons.	(S)	118,293				kkg	(pounds shipped annually/2,200)
3.	Fraction shipped by each mode of transportation.[a]	(F)	0.67	0.21		0.0002		Calculated using data from USDOC 1981a, or from ICC waybill data for rail only
4.	Total quantity shipped annually by each mode of transportation.	(W)	79,256	24,842		24	kkg	W = S x F
5.	Average quantity per shipment.	(V)	22.7	75.7		0.01	kkg	Genereaux et al. 1984, ICC waybill data for rail only, or USDOT 1981a, Table 4
6.	Average shipment distance for each mode of transportation.	(M)	215	622		1,000	Miles per shipment	Appendix C; or use ICC waybill data for rail only
7.	Annual number of shipments.	(Y)	3,491	328		2,400	Shipments per year	$Y = \frac{W}{V}$
8.	Accident rate for each mode of transportation.	(A)	1.2×10^{-6}	6.0×10^{-6}	b	5.0×10^{-9}	Accident/mile	USEPA 1985, USDOT 1986a, USDOT 1987

Figure 3. Sample worksheet for predicting the amount of DEHP released annually because of rail, tank truck, and air transport accidents.

Step No.	Item/Parameter	Abbreviation	Values of Parameters				Units	Reference/Comment
			Truck	**Rail**	**Waterborne**	**Air**		
9.	Probability of a release, given an accident, for each mode of transportation.	(P)	0.29	0.130	[b]	1.0	Release per accident	P-values for the following: Tanker truck 0.29 Truck (steel drum containers, etc.) 0.26 Rail 0.130 Air 1.0
10.	Annual number of releases.	(N)	0.26	0.15		0.01	Releases/ year	N = M x Y x A x P
11.	Fraction of container contents released.[a]	(R)	0.324	0.107		0.28		Options: Tables 6, 7, and 8[c]
12.	Quantity of chemical released annually by each mode of transportation.	(Q)	1.9	1.3		2.8×10^{-5}	kkg	Q = V x N x R
13.	Total quantity of chemical released annually.	(Q_{Total})						
			Q_{Truck}	1.9				
			+ Q_{Rail}	1.3				
			+ $Q_{Waterborne}$					
			+ Q_{Air}	2.8×10^{-5}				
				3.2	= Total quantity released.		kkg	

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[a] Dimensionless factor.

[b] Barge data are not currently available; see Section 3.1 for possible future sources of this information.

[c] Table 6 is used when mode of transportaton is known but physical state and DOT hazard class are unknown. Table 7 is used when mode of transportation and physical state are known but DOT hazard class is unknown. Table 8 is used when mode of transportation, physical state, and DOT hazard class are all known.

Figure 3. (continued)

Step 1. DEHP is not regulated by the DOT. Therefore, there is no DOT hazard class designation for DEHP. The STCC code for DEHP is 2899991 (STCC 1972), and its physical state at standard conditions is liquid. The CAS registry number is 117-81-7 (USEPA 1986).

Step 2. Currently USITC does not list quantities of DEHP produced or sold, but incorporates these data with all dioctylphthalate data. In other words, DEHP production and sales data are not listed separately. In order to estimate the quantities produced and sold, the ratios of DEHP (produced and sold) to the total quantity of all dioctylphthalates (produced and sold) were derived for 1979, 1980, 1981, and 1982. These ratios were averaged and then multiplied by the dioctylphthalate volumes reported in USITC 1986. This seems a reasonable approach, as plasticizer production has remained relatively constant over the past five years. Based on these estimates, 260,245,000 pounds of DEHP were sold and therefore assumed to have been shipped in 1985.

Step 3. The quantities of DEHP that are shipped by each mode of transportation can be estimated using data from the CTS Summary for 1977 (USDOC 1981a). The STCC code for DEHP, 2899991, corresponds to TCC code 28999 in the 1977 CTS Summary (see Table 9 of this report). The total quantity of STCC 28999 commodities shipped in 1977 was 5,253,000 tons. Of this quantity, 3,503,000 tons (67 percent) were shipped by truck (including private trucks and both ICC and non-ICC motor carriers). Another 1,080,000 tons (21 percent) were transported by rail, and 398,000 tons (8 percent) were transported by waterborne transportation. An additional 1,000 tons (0.02 percent) were carried by air, and the remaining quantity was transported by other modes of transportation.

Step 4. Using the data obtained in Steps 2 and 3 above, one can calculate that in 1985, 79,256 kkg (118,293 kkg x 0.67) of DEHP was transported by truck, and 24,842 kkg (118,293 kkg x 0.21) were transported by rail. Additionally, 24 kkg (118,293 kkg x 0.0002) were carried by air. (This does not account for 9,463 kkg (118,293 x 0.08) transported by waterborne vessels and the remaining quantity transported by other modes of transportation.)

Table 9. Shipping Patterns for STCC 28999

	Value (million dollars)	Tons (thousand)	Ton-miles (million)
Chemical products, nec.	3,039	5,253	1,804
Rail	475	1,080	672
Motor carrier	1,382	1,417	452
Motor carrier, ICC	1,341	1,363	433
Motor carrier, non-ICC	41	54	20
Private truck	652	2,086	305
Air	7	1	1
Water	216	398	370
Pipeline	58	225	2
Parcel delivery	51	2	2
Other and unknown	198	43	(2)

Source: USDOC 1981a.

Step 5. The capacity of rail tank cars carrying DEHP, a liquid chemical, is assumed to be 20,000 gallons (Genereaux et al. 1984). Because the density of DEHP is approximately 1 kg/L, each tank car would hold 75,700 kilograms (75.7 kkg) DEHP (20,000 gal/car x 3.785 L/gal x 1 kg/L).

An average tank truck capacity of 6,000 gallons (22.7 kkg DEHP) is assumed (per Genereaux et al. 1984).

The average quantity shipped by air was 0.01 kkg. This was determined from Table 4 of USDOC (1981a).

Step 6. The average shipping distances of DEHP transported by rail and tank truck can be estimated using Method C-1 from Appendix C of this report and data from Table 2 of the 1977 CTS Summary, USDOC 1981a (see Table 9 of this report). CTS Summary data for TCC code 28999 are used to represent DEHP, as discussed in Step 3 above.

For shipments of DEHP by rail, the average shipping distance would be 622 miles (672,000,000 ton-miles/1,080,000 tons shipped).

The value for shipping distance by truck is calculated using a weighted average of shipping distances calculated for the two major truck categories listed in the CTS Summary: motor carriers (ICC and non-ICC combined) and private trucks. The average shipping distance for motor carriers is 318 miles (452,000,000 ton-miles/1,417,000 tons shipped). Motor carriers account for 40 percent of the total tons of TCC category 28999 shipped by truck. The average shipping distance for private trucks (60 percent of the total tons of TCC category 28999 shipped by truck) is 146 miles (305,000,000 ton-miles/2,086,000 tons shipped).

The weighted average shipping distances for trucks carrying TCC 28999 commodities would be 215 miles [(318 miles x 0.40) + (146 miles x 0.60)].

For air, the average shipping distance of 1,000 miles was determined by using Method C-3 in Appendix C.

Step 7. The annual number of rail shipments of DEHP would be 328 (24,842 kkg/75.7 kkg/shipment).

For tank trucks, the annual number of shipments is 3,491 (79,256 kkg/22.7 kkg/shipment).

For air transport, the annual number of shipments is 2,400 (24 kkg/0.01 kkg/shipment).

Step 8. The accident rate for rail is 6.0 x 10^{-6} accidents/mile (USDOT 1986a); for trucks, it is 1.2 x 10^{-6} accidents/mile (USEPA 1985); and for air, it is 5.0 x 10^{-9} accidents/mile (USDOT 1987).

Step 9. For rail transport, the probability of a release, given an accident, is 0.130 release/accident (USDOT 1986a). For tank trucks, the probability of a release, given an accident, is 0.29 release/accident (USEPA 1985). For air, the probability of a release, given an accident, is assumed to be 1.0.

Step 10. The estimated annual number of rail releases is:

622 miles/shipment x 6.0 x 10^{-6} accidents/mile
x 0.13 releases/accident x 328 shipments/year
= 0.16 releases/year.

The annual number of predicted releases of DEHP from tank trucks is:

215 miles/shipment x 1.2 x 10^{-6} accidents/mile
x 0.29 releases/accident x 3,491 shipments/year
= 0.26 releases/year.

The annual number of predicted releases of DEHP from air transport is:

1,000 miles/shipment x 5.0 x 10^{-9} accidents/mile
x 1.0 release/accident x 2,400 shipments/year
= 0.01 releases/year.

Step 11. Because the physical state of DEHP and the applicable modes of transportation are known but no DOT hazard class applies to DEHP, the correct source of data on fractions of container released is Table 7. For rail, the mean value of fraction of container contents released is 0.107, and for truck, it is 0.324. For air transport, the mean value of fraction of container contents released is 0.276.

Step 12. The predicted quantity of DEHP released because of rail accidents is:

0.16 release/year x 0.107 fraction of container released x 75.7 kkg/container = 1.3 kkg/yr.

The predicted quantity of DEHP released because of tank truck accidents is:

0.26 release/year x 0.324 fraction of container contents released x 22.7 kkg/shipment = 1.9 kkg/yr.

The predicted quantity of DEHP released because of air accidents is:

0.01 release/year X 0.28 fraction of container contents released x 0.01 kkg/shipment = 2.8 x 10^{-5} kkg/yr.

Step 13. Summing the calculated values for rail and tank truck releases, the total amount of DEHP released annually is 3.2 kkg (1.3 kkg + 1.9 kkg). Note that the quantity of DEHP released because of air accidents is 5 orders of magnitude less than the quantities released by truck and rail transport. It is therefore not summed with these two modes of transportation.

Alternatively, if it is assumed that all DEHP shipped by truck is shipped in 55-gallon drums, each drum would contain 208 kilograms (55 gal x 3.785 L/gal x 1 kg/L), or 0.21 kkg. If it is assumed that the steel drums are transported in 20-cubic yard trucks, the total capacity of each truck would be 4,039 gallons (20 yd^3 x 27 ft^3/yd^3 x 7.48 gal/ft^3). The average quantity per shipment would be 15,288 kilograms (4,039 gal x 3.785 L/gal x 1 kg/L) or 15.3 kkg. This would be equivalent to a capacity of 73 55-gallon drums. The annual number of shipments would be 5,180 (79,256 kkg shipped by truck/15.3 kkg per shipment).

In Section 3.1, Step 9, it was estimated that, given an accident, the probability of a release from a steel drum (container) being transported by truck is 0.26. For the purposes of this method, it is assumed that all steel drums on an individual truck shipment would be equally susceptible to damage during an accident. Also, the accident rate for trucks is 1.2 x 10^{-6} accidents per mile (USEPA 1985). If an average shipping distance of 215 miles (see Step 6) is assumed, the annual number of releases per year from trucks carrying steel drums would be:

5,180 shipments/year x 215 miles/shipment x 1.2 x 10^{-6} accidents/mile x 0.26 release/accident = 0.3 release per year.

Since the fraction of container contents released (Table 7) is 0.324, then the predicted amount of DEHP released from drums is 0.3 release/year x 0.21 kkg/drum x 73 drums/shipment x 0.324 drum/release = 1.52 kkg.

If we compare the total estimated quantity of DEHP released by rail tank cars and tank trucks (3.2 kkg = 1.3 kkg + 1.9 kkg) with the total estimated quantity released by rail tank cars and steel drums in trucks (2.8 kkg = 1.3 kkg + 1.5 kkg), we can predict a probable range of 2.8 to 3.2 kkg of DEHP, released annually because of combined releases from rail and truck accidents. These values may underestimate the expected total releases of DEHP inasmuch as releases during waterborne transportation and "other" modes of transportation were not included because of a lack of information.

3.2.2 Expected Releases of Ethylene Oxide During Railroad Transportation Accidents

This section illustrates the use of ICC waybill data and other sources of information for calculating expected releases of chemicals by rail only. Ethylene oxide is used as an example because shipping data for this chemical are available in the nonconfidential files of the ICC waybill data base.

(1) Background. Ethylene oxide is a colorless, flammable gas at ordinary room temperature and pressure. Also called Oxirane and Anprolene, it is used as a fumigant for foodstuffs and textiles. Ethylene oxide is used as a sterilant for surgical instruments and an agricultural fungicide. It is a precursor in ethylene glycol synthesis and a starting material for the production of acrylonitrile and non-ionic surfactants. According to USITC (1986), 5,430,359,000 pounds (24,468,427 kkg) of ethylene oxide were produced in 1985. Sales of ethylene oxide accounted for only 615,170,000 pounds (279,623 kkg). Presumably, this is the quantity of ethylene oxide that was shipped. SRI (1987) lists 12 manufacturers of ethylene oxide. These manufacturers, along with their locations and annual capacities, are listed in Table 10.

Because ethylene oxide boils at 10.7°C (Windholz 1983), it is transported in pressurized containers, i.e., railroad tank cars, tank trucks, and pressurized cylinders. Estimated releases of ethylene oxide from railroad tank cars are presented below.

Table 10. Locations and Capacities of Ethylene Oxide Manufacturing Plants, January 1, 1987

Plant	Location	Annual capacity (millions of pounds)
BASF Corporation Chemicals Division Industrial & Performance Chemicals Group Industrial Organics Business	Geismar, Louisiana	495
Celanese Corporation Celanese Chemical Company, Inc.	Clear Lake, Texas	450
Dow Chemical U.S.A.	Plaquemine, Louisiana	465
Eastman Kodak Company Eastman Chemical Products, Inc., subsidiary Texas Eastman Company	Longview, Texas	200
ICI American Holdings Inc. ICI Americas Inc. ICI Specialty Chemicals Group ICI Specialty Products	Bayport, Texas	500
National Distillers and Chemical Corporation Chemicals Division USI Chemicals Company, division	Morris, Illinois	230
PD Glycol	Beaumont, Texas	455
Shell Oil Company Shell Chemical Company, division	Geismar, Louisiana	800
SunOlin Chemical Company	Claymont, Delaware	100
Texaco Inc. Texaco Chemical Company, subsidiary	Port Neches, Texas	700
Union Carbide Corporation Industrial Chemicals Division	Seadrift, Texas	670
	Taft, Louisiana	1,325
Total		6,390

Source: SRI 1987.

(2) Estimated releases of ethylene oxide from railroad tank cars where ICC waybill data were used. The following example demonstrates the use of ICC waybill and other data to calculate the expected quantity of ethylene oxide that would be accidentally released from railroad tank cars over a one-year period. The example is presented in steps corresponding to those options in the general method (Section 3.1) in which ICC waybill data are used. Figure 4 is a sample worksheet that has been completed using data specific to transportation of ethylene oxide by railroad tank cars.

Step 1. Ethylene oxide is classified as a flammable liquid by the DOT (Table 11, USDOT 1986b). Its STCC code is 2818239 and its physical state at standard conditions is gas (b.p. 10.7°C). The CAS registry number is 75-21-8 (USEPA 1986).

Step 2. Based on the 1985 ICC 1 percent waybill data presented in Table 12, there were an estimated 6,880 railroad tank car shipments of ethylene oxide during 1985 and the average car contained 71.3 kkg (78.4 tons (1.1 ton/metric tons)) ethylene oxide. Therefore, the estimated annual quantity shipped by rail is 71.3 kkg/car x 6,880 cars = 490,509 kkg. Note that this quantity is almost twice the amount reported as sold in USITC (1986). This may indicate that (1) multiple counting occurs if a volume of ethylene oxide is hauled by more than one rail carrier from its point of origin to its final destination, and (2) companies ship ethylene oxide by rail to facilities under the same ownership for further processing.

Steps 3 and 4. Because the quantity shipped annually by rail is available directly from ICC waybill data, Step 3 of the method can be omitted, and the value from Step 2 for quantity shipped by rail (490,509 kkg) is entered on the worksheet which is Step 4.

Step 5. Based on ICC data from Table 12, the average quantity of ethylene oxide shipped per rail car is 71.3 kkg (79.0 tons/1.1 ton/kkg).

Step 6. Using ICC data from Table 12, the average shipment distance by rail is 946 miles (6,508,700 car miles/6,880 tank cars).

Step 7. The annual number of rail shipments reported in ICC waybill data (Table 12) is 6,880.

Step 8. The 1985 average accident rate for rail transportation is 6.0 x 10^{-6} accidents per mile (USDOT 1986a).

Step No.	Item/Parameter	Abbreviation	Values of Parameters				Units	Reference/Comment
			Truck	Rail	Waterborne	Air		
1.	Identify:							
	Chemical name.		Ethylene oxide					
	DOT hazard class.		Flammable liquid					49 CFR 172.101 (USDOT 1986b)
	Standard Transportation Commodity Code (STCC).		2818239					STCC 1972; National Motor Freight Classification Board Table 3
	Physical state.		Liquid (under pressure)					
	CAS registry number.							CRC 1986, USEPA 1986
2.	Total annual quantity shipped.		(By rail) 1.08×10^{9}				pounds	Options: USITC, SRI, Chemical Producers' Data Base, or ICC
	Convert to metric tons.	(S)					kkg	(pounds shipped annually/2,200)
3.	Fraction shipped by each mode of transportation.[a]	(F)		omit				Calculated using data from USDOC 1981a; or from ICC waybill data for rail only
4.	Total quantity shipped annually by each mode of transportation.	(W)		490,509			kkg	W = S x F
5.	Average quantity per shipment.	(V)		71.3			kkg	Genereaux et al. 1984, ICC waybill data for rail only, or USDOT 1981a Table 4
6.	Average shipment distance for each mode of transportation.	(M)		946			Miles per shipment	Appendix C; or use ICC waybill data for rail only
7.	Annual number of shipments.	(Y)		6,880			Shipments per year	$Y = \frac{W}{V}$
8.	Accident rate for each mode of transportation.	(A)	1.2×10^{-6}	6.0×10^{-6}	[b]	5.0×10^{-9}	Accident/mile	USEPA 1985, USDOT 1986a, USDOT 1987

Figure 4. Sample worksheet for predicting the amount of formaldehyde released because of railroad accidents.

Step No.	Item/Parameter	Abbreviation	Values of Parameters				Units	Reference/Comment
			Truck	**Rail**	**Waterborne**	**Air**		
9.	Probability of a release, given an accident, for each mode of transportation.	(P)		0.13	b		Release per accident	P-values for the following: Tanker truck 0.29 Truck (steel drum containers, etc.) 0.26 Rail 0.130 Air 1.0
10.	Annual number of releases.	(N)		5.0			Releases/ year	N = M x Y x A x P
11.	Fraction of container contents released.[a]	(R)		0.127				Options: Tables 6, 7, and 8[c]
12.	Quantity of chemical released annually by each mode of transportation.	(Q)		45.3			kkg	Q = V x N x R
13.	Total quantity of chemical released annually.	(Q_{Total})						
			Q_{Truck}					
			+ Q_{Rail}	45.3				
			+ $Q_{Waterborne}$					
			+ Q_{Air}					
					= Total quantity released (kkg).		kkg	

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[a] Dimensionless factor.

[b] Barge data are not currently available; see Section 3.1 for possible future sources of this information.

[c] Table 6 is used when mode of transportaton is known but physical state and DOT hazard class are unknown. Table 7 is used when mode of transportation and physical state are known but DOT hazard class is unknown. Table 8 is used when mode of transportation, physical state, and DOT hazard class are all known.

Figure 4. (continued)

Table 11. Sample DOT Packaging Requirements Including Ethylene Oxide

§172.101 Hazardous Materials Table—Contd.

(1)	(2)	(3)	(3A)	(4)	(5)		(6)		(7)		
					Packaging		Maximum net quantity in one package		Water shipments		
+/A/W	Hazardous materials descriptions and proper shipping names	Hazard class	Identification number	Label(s) required (if not excepted)	(a) Exceptions	(b) Specific requirements	(a) Passenger carrying aircraft or railcar	(b) Cargo aircraft only	(a) Cargo vessel	(b) Passenger vessel	(c) Other requirements
	Ethyl borate	Flammable liquid	UN1176	Flammable liquid	173.118	173.119	1 quart	10 gallons	1,2	1	Keep dry
	Ethyl butyl acetate	Combustible liquid	UN1177	None	173.118a	None	No limit	No limit	1,2	1,2	
	Ethyl butyl ether	Flammable liquid	UN1179	Flammable liquid	173.118	173.119	1 quart	10 gallons	1,2	1	
	Ethyl butyraldehyde	Flammable liquid	UN1178	Flammable liquid	173.118	173.119	1 quart	10 gallons	1,2	1	
	Ethyl butyrate	Flammable liquid	UN1180	Flammable liquid	173.118	173.119	1 quart	10 gallons	1,2	1,2	
	Ethyl chloride	Flammable liquid	UN1037	Flammable liquid	None	173.123	Forbidden	See 173.123	1,2	1	Segregation same as for flammable gases
	Ethyl chloroacetate	Combustible liquid	UN1181	None	173.118a	None	No limit	No limit	1,2	1,2	
	Ethyl chloroformate (chlorocarbonate)	Flammable liquid	UN1182	Flammable liquid and Poison	None	173.288	Forbidden	5 pints	1,2	1	
	Ethyl chlorothioformate	Corrosive material	UN2826	Corrosive	173.244	173.245 173.245a	1 quart	1 quart	1,2	1	
	Ethyl crotonate	Flammable liquid	UN1862	Flammable liquid	173.118	173.119	1 quart	10 gallons	1,2	1	
	Ethyl dichlorosilane	Flammable liquid	UN1183	Flammable liquid	None	173.135	Forbidden	5 pints	1,2	1	
	Ethylene *or* Ethylene, compressed	Flammable gas	UN1962	Flammable gas	173.306	173.304	Forbidden	300 pounds	1,2	4	Stow away from living quarters.
	Ethylene chlorohydrin	Poison B	UN1135	Poison	173.345	173.346 173.3a	1 quart	55 gallons	1,2	1	Segregation same as for flammable liquids
	Ethylene, refrigerated liquid *(cryogenic liquid)*	Flammable gas	UN1038	Flammable gas	None	173.318 173.319	Forbidden	Forbidden	1	5	Stow away from living quarters.
	Ethylenediamine	Corrosive material	UN1604	Corrosive	173.244	173.245	1 quart	1 quart	1,2	1,2	
	Ethylene diamine diperchlorate	Forbidden									
	Ethylene dibromide	Poison B	UN1605	Poison	173.345	173.346	1 quart	55 gallons	1,2	1,2	Stow away from living quarters
	Ethylene dichloride	Flammable liquid	UN1184	Flammable liquid	173.118	173.119	1 quart	10 gallons	1,2	1	
	Ethylene glycol diethyl ether *(diethyl 'Cellosolve')*	Flammable liquid	UN1153	Flammable	173.118	173.119	1 quart	10 gallons	1,2	1,2	
	Ethylene glycol dinitrate	Forbidden									
	Ethylene glycol monoethyl ether *('Cellosolve')*	Combustible liquid	UN1171	None	173.118a	None	No limit	No limit	1,2	1,2	
	Ethylene glycol monoethyl ether acetate *('Cellosolve acetate')*	Combustible liquid	UN1172	None	173.118a	None	No limit	No limit	1,2	1,2	
	Ethylene glycol monomethyl ether *(methyl 'Cellosolve')*	Combustible liquid	UN1188	None	173.118a	None	No limit	No limit	1,2	1,2	
	Ethylene glycol monomethyl ether acetate *(methyl 'Cellosolve acetate')*	Combustible liquid	UN1189	None	173.118a	None	No limit	No limit	1,2	1,2	
	Ethyleneimine, inhibited	Flammable liquid	UN1185	Flammable liquid and Poison	None	173.139	Forbidden	5 pints	1,2	1	
	Ethylene oxide	Flammable liquid	UN1040	Flammable liquid	None	173.124	Forbidden	See 173.124	1,2	1	Segregation same as for flammable gases
	Ethyl ether	Flammable liquid	UN1155	Flammable liquid	None	173.119	Forbidden	10 gallons	1,3	5	
	Ethyl formate	Flammable liquid	UN1190	Flammable liquid	173.118	173.119	1 quart	10 gallons	1,3	4	
	Ethylhexaldehyde	Combustible liquid	UN1191	None	173.118a	None	No limit	No limit	1,2	1,2	
	Ethyl hydroperoxide (explodes above 100 deg C)	Forbidden									
	Ethyl lactate	Combustible liquid	UN1192	None	173.118a	None	No limit	No limit	1,2	1,2	
	Ethyl mercaptan	Flammable liquid	UN2363	Flammable liquid	None	173.141	Forbidden	10 gallons	1,2	1	
	Ethyl methyl ether	Flammable liquid	UN1039	Flammable liquid	None	173.119	Forbidden	10 gallons	1,3	1	Segregation same as for flammable gases
	Ethyl methyl ketone	Flammable liquid	UN1193	Flammable liquid	173.118	173.119	1 quart	10 gallons	1,2	1	
	Ethyl nitrate (nitric ether)	Flammable liquid	NA1993	Flammable liquid	173.118	173.119	Forbidden	Forbidden	1,2	1	
	Ethyl nitrite (nitrous ether)	Flammable liquid	UN1194	Flammable liquid	None	173.119	Forbidden	Forbidden	1,3	5	
	Ethyl perchlorate	Forbidden									

Source: USDOT 1986b.

Table 12. Shipments of Ethylene Oxide by Railroad Tank Cars Estimated from ICC Data

Number of tank cars	6,880
Total tons lading	539,560
Total car-miles	6,508,560
Average tons/car	78.4
Average haul car-miles	946

Source: ICC Waybill Sample (ICC 1985).

Step 9. The probability of a release given an accident is 0.13 (USDOT 1986a).

Step 10. The annual number of expected releases of ethylene oxide during rail transportation is:

946 miles/shipment x 6.0 x 10^{-6} accidents/mile
x 0.13 release/accident x 6,880 shipments/year =
5.0 releases/year.

Step 11. Because the physical state (liquid), mode of transportation (rail), and DOT hazard class (flammable liquid commodity class number 25 on Table 5) are known, then the fraction of the container contents released during an accident can be found in Table 8. This value is 0.127.

Step 12. The estimated quantity of ethylene oxide released annually because of rail accidents is:

5.0 releases/year x 71.3 kkg/container
x 0.127 container/release = 45.3 kkg/yr.

3.2.3 Expected Releases of Formaldehyde During Transportation Accidents

(1) Background. Commercial formaldehyde is produced and shipped as an aqueous solution containing 37 percent formaldehyde and up to 10 percent methanol. Formaldehyde in aqueous solutions rapidly hydrates to form methylene glycol and a series of low molecular weight polymeric polyoxymethylene glycols. The methanol is added to prevent the formaldehyde from polymerizing. The concentration of formaldehyde as the aldehyde in aqueous solutions has been found to be well under 0.1 percent (Walker 1975).

The most recent estimate available of annual U.S. production of 37 percent formaldehyde solution is 5,606,140,000 pounds (2,548,245 kkg) (USITC 1986). This amount, which represents 1985 production, is equivalent to 66 percent of the January 1, 1986, production capacity of 8,584,000,000 pounds (3,901,818 kkg) reported by SRI (SRI 1986). At the beginning of 1986, production capacity for formaldehyde was distributed among 15 manufacturers and 47 facility locations, as summarized in Table 13 (SRI 1986). The production capacity represented in Table 13 was geographically concentrated in the southeastern and southwestern states. It is not known, however, how actual production and sales were distributed among these facilities.

The quantity of 37 percent formaldehyde solution sold and presumably shipped in 1985 was 1,742,409,000 pounds (792,040 kkg) (USITC 1986). This quantity sold represents 31 percent of reported production (per

Table 13. Locations and Capacities of Formaldehyde Manufacturing Plants, January 1, 1986

Plant name	Location	Annual capacity (thousand metric tons)
Borden Inc.		
Borden Chemical Division		
Adhesives and Chemicals Division	Demopolis, Alabama	43
	Diboll, Texas	36
	Fayetteville, North Carolina	107
	Fremont, California	102
	Kent, Washington	36
	La Grande, Oregon	30
	Louisville, Kentucky	36
	Missoula, Montana	41
	Sheboygan, Wisconsin	59
	Springfield, Oregon	109
Petrochemicals Division	Geismar, Louisiana	114
BTL of Arkansas, Inc.	Malvern, Arkansas	50
Celanese Corporation		
Celanese Chemical Company	Newark, New Jersey	53
Celanese Specialty Operation		
Celanese Engineering Resins Division	Bishop, Texas	818
Chembond Inc.	Andalusia, Alabama	32
	Moncure, North Carolina	55
	Springfield, Oregon	64
	Winnfield, Louisiana	32
E.I. DuPont de Nemours & Company, Inc.		
Chemicals and Pigments Department	Belle, West Virginia	227
	Grasseli, New Jersey	73
	Healing Springs, North Carolina	100
	La Porte, Texas	145
	Toledo, Ohio	123
GAF Corporation		
Chemical Products	Calvert City, Kentucky	45
	Texas City, Texas	45

Table 13. (continued)

Plant name	Location	Annual capacity (thousand metric tons)
Georgia-Pacific Corporation		
Chemical Division	Albany, Oregon	55
	Columbus, Ohio	75
	Conway, North Carolina	48
	Crossett, Arkansas	75
	Lufkin, Texas	48
	Russellville, South Carolina	99
	Taylorsville, Mississippi	55
	Vienna, Georgia	48
Hercules Incorporated		
Operations Division	Louisiana, Missouri	79
International Minerals & Chemical Corporation		
IMC Chemical Group		
Industrial Chemicals Division	Seiple, Pennsylvania	61
Monsanto Company		
Monsanto Chemical Company	Addyston, Ohio	52
	Chocolate Bayou, Texas	82
	Springfield, Massachusetts	134
Nuodex Inc.	Fords, New Jersey	84
Perkins Industries, Inc.	Vicksburg, Mississippi	25
Reichhold Chemicals, Inc.	Hampton, South Carolina	23
	Houston, Texas	105
	Kansas City, Kansas	23
	Tuscaloosa, Alabama	33
Rogue Valley Polymers, Inc.	White City, Oregon	91
Wright Chemical Corporation	Acme, North Carolina	36
TOTAL		3,902

Source: SRI 1986.

USITC 1986) and approximately 20 percent of production capacity (per SRI 1986).

(2) Estimating releases of formaldehyde from tanks trucks. In addition to being shipped by rail, formaldehyde solution is also transported by tank truck. The following example describes the application of the general method (Section 3.1) to predicting the annual release of formaldehyde resulting from tank truck accidents. Figure 5 is a worksheet that has been filled out using data on formaldehyde transport by tank truck. Following Step 13, an alternative calculation of releases from trucks carrying steel drums is presented.

Step 1. The DOT hazard class is combustible liquid, the STCC number is 2818144 (STCC 1972), and the physical state is liquid. The CAS registry number is 50-00-0 (USEPA 1986).

Step 2. The USITC (1986) reports that 1,742,409,000 pounds of formaldehyde were sold in 1985. Assuming the amount sold was the amount shipped, and converting to metric tons, the estimated quantity of formaldehyde shipped in 1985 was 792,004 kkg.

Step 3. The STCC code for formaldehyde, 2818144, corresponds most closely to TCC code 2818, Miscellaneous Organic Chemicals, in the CTS Summary for 1977 (USDOC 1981a). Because the quantity shipped is known, the CTS Summary data (USDOC 1981a) can be used to estimate the quantity shipped by truck. According to Table 2 of the CTS Summary for 1977, 10,273,000 tons of commodity code TCC 2818 were transported by truck (the quantity carried by motor carriers, plus the quantity carried by private truck). That amount was equivalent to 32 percent of the total quantity (32,324,000 tons) of this TCC category that was transported in 1977.

Step 4. It is assumed that 32 percent of the total formaldehyde solution shipped was shipped by truck; this is equivalent to 253,441 kkg (0.32 x 792,004 kkg) of formaldehyde solution transported by truck.

Step 5. The density of a 37 percent solution of formaldehyde is 1.083 kilograms/liter (Aldrich 1983). A 6,000-gallon truck (average capacity, per Genereaux et al. 1984) would contain 24,595 kilograms formaldehyde solution (6,000 gal x 3.785 L/gal x 1.083 kg/L). This is equivalent to 24.6 kkg per truck shipment.

Step No.	Item/Parameter	Abbreviation	Values of Parameters				Units	Reference/Comment
			Truck	**Rail**	**Waterborne**	**Air**		
1.	Identify:							
	Chemical name.		Formaldehyde					
	DOT hazard class.		Combustible liquid (containers >110 gal)					49 CFR 172.101 (USDOT 1986b)
	Standard Transportation Commodity Code (STCC).		2818144					STCC 1972; National Motor Freight Classification Board Table 3
	Physical state.		Liquid					
	CAS registry number.		50-00-0					CRC 1986, USEPA 1986
2.	Total annual quantity shipped.		1,742,409,000				pounds	Options: USITC, SRI, Chemical Producers' Data Base, or ICC
	Convert to metric tons.	(S)	792,004				kkg	(pounds shipped annually/2,200)
3.	Fraction shipped by each mode of transportation.[a]	(F)	0.32					Calculated using data from USDOC 1981a, or from ICC waybill data for rail only
4.	Total quantity shipped annually by each mode of transportation.	(W)	253,441				kkg	W = S x F
5.	Average quantity per shipment.	(V)	24.6				kkg	Genereaux et al. 1984, ICC waybill data for rail only, or USDOT 1981a, Table 4
6.	Average shipment distance for each mode of transportation.	(M)	309				Miles per shipment	Appendix C; or use ICC waybill data for rail only
7.	Annual number of shipments.	(Y)	10,302				Shipments per year	$Y = \frac{W}{V}$
8.	Accident rate for each mode of transportation.	(A)	1.2×10^{-6}	6.0×10^{-6}	[b]	5.0×10^{-9}	Accident/mile	USEPA 1985, USDOT 1986a, USDOT 1987

Figure 5. Sample worksheet for predicting the amount of formaldehyde released because of tank truck accidents.

Step No.	Item/Parameter	Abbreviation	Values of Parameters: **Truck**	**Rail**	**Waterborne**	**Air**	Units	Reference/Comment
9.	Probability of a release, given an accident, for each mode of transportation.	(P)	0.29		b		Release per accident	P-values for the following: Tanker truck 0.29 Truck (steel drum, containers, etc.) 0.26 Rail 0.130 Air 1.0
10.	Annual number of releases.	(N)	1.1				Releases/ year	N = M x Y x A x P
11.	Fraction of container contents released.[a]	(R)	0.226					Options: Tables 6, 7, and 8[c]
12.	Quantity of chemical released annually by each mode of transportation.	(Q)	6.1				kkg	Q = V x N x R
13.	Total quantity of chemical released annually.	(Q_{Total})						
		Q_{Truck}		6.1				
		$+ Q_{Rail}$						
		$+ Q_{Waterborne}$						
		$+ Q_{Air}$						
					= Total quantity released.		kkg	

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[a] Dimensionless factor.

[b] Barge data are not currently available; see Section 3.1 for possible future sources of this information.

[c] Table 6 is used when mode of transportaton is known but physical state and DOT hazard class are unknown. Table 7 is used when mode of transportation and physical state are known but DOT hazard class is unknown. Table 8 is used when mode of transportation, physical state, and DOT hazard class are all known.

Figure 5. (continued)

Step 6. The average shipping distance of formaldehyde transported by truck can be estimated using Method C-1 from Appendix C of this report and data from Table 2 of the 1977 CTS Summary (USDOC 1981a). CTS Summary data for TCC code 2818 (Miscellaneous Organic Chemicals) are used to represent shipping patterns of formaldehyde, as discussed in Step 3 above.

The value for shipping distance by truck is calculated using a weighted average of shipping distances calculated for the two major truck categories listed in the CTS Summary: motor carriers (ICC and non-ICC) and private truck. The average shipping for motor carriers is 320 miles (2,338,000,000 ton-miles/7,302,000/tons shipped). Motor carriers account for 71 percent of the total tons of TCC category 2818 transported by truck. The average shipping distance for private truck (29 percent of the total tons of TCC category 2818 shipped by truck) is 283 miles (841,000,000 ton-miles/2,971,000 tons shipped). The weighted average shipping distance for trucks carrying TCC 2818 commodities would be 309 miles ((320 x 0.71) + (283 x 0.29)).

Step 7. If each tank truck contains 24.6 kkg of solution, then 10,302 shipments would be needed to transport 253,441 kkg of formaldehyde solution each year.

Step 8. The average accident rate for trucks is 1.2×10^{-6} accidents per mile (USEPA 1985).

Step 9. The probability of a release, given an accident, for a tank truck is 0.29 (USEPA 1985).

Step 10. The expected number of releases each year would be:

309 miles/shipment x 1.2×10^{-6} accidents/mile
x 0.29 release/accident x 10,302 shipments/year
= 1.1 releases/year.

Step 11. Since the DOT hazard class (commodity class number 20 on Table 5), mode of transportation, and physical state are known, the percent of container released is found in Table 8. This value is 0.226.

Step 12. The predicted quantity of formaldehyde solution released annually because of tank truck accidents is:

1.1 releases/year x 0.226 container/released
x 24.6 kkg/container = 6.1 kkg.

(3) Estimating releases of formaldehyde solution from truck transport in steel drums. Not all formaldehyde truck shipments are made in tank trucks; glass carboys and stainless steel drums are also used as containers. If it is assumed that the formaldehyde solution is transported by steel drums and that tank trucks are not used, then the estimate of releases is calculated as follows: According to Table 11 (USDOT 1986b), formaldehyde solution transported in containers of 110-gallon capacity or less is regulated under DOT hazard class, Other Regulated Material-A (ORM-A). If 110-gallon drums of 37 percent formaldehyde are transported in 20 cubic yard trucks, the total capacity of each truck would be 4,039 gallons (20 yd^3 x 27 ft^3/yd^3 x 7.48 gal/ft^3). This would be equivalent to a capacity of 37 110-gallon drums. The average quantity per shipment would be 16,556 kilograms, or 16.6 kkg (4,039 gal x 3.785 L/gal x 1.083 kg/L). The annual number of shipments this size would be 15,268 (253,441 kkg shipped by truck/16.6 kkg per shipment).

The probability of a release, given an accident, for trucks transporting steel drums is 0.26 (ICF 1984). For the purposes of this calculation, it is assumed that, given a nontrivial accident, all of the drums carried by a truck during an individual shipment would be equally subject to damage and potential release. If an average shipping distance of 309 miles and a truck accident rate of 1.2 x 10^{-6} accidents/mile (USEPA 1985) are assumed, the expected annual number of releases is:

309 miles/shipment x 1.2 x 10^{-6} accidents/mile
x 15,946 shipments/year x 0.26 release/accident
= 1.5 releases/year.

Because formaldehyde solution is classified under ORM-A (commodity Class 2 from Table 5), and is transported as a liquid by truck, Table 8 indicates that, given a release, 47.3 percent of the container contents will be lost during an accident involving a release. If there are 1.5 releases per year, then the average quantity of formaldehyde released per year is:

1.5 releases/year x 16.6 kkg/shipment
x 0.473 fraction released
= 11.8 kkg.

(4) Summary. These results and those obtained for tank trucks indicate that the expected annual quantity of formaldehyde solution released as a result of truck accidents would range from 6.1 kkg (tank trucks) to 11.8 kkg (steel drums). This estimate does not include waterborne or other modes of transportation.

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APPENDIX A

Department of Transportation
Hazard Classes

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Appendix A

Department of Transportation Hazard Classes

Hazard class	Definition	Examples
Flammable liquid	Any liquid having a flash point below 100° F as determined by tests listed in 49 CFR 173.115(d). Exceptions are listed in 49 CFR 173.115(a).	Ethyl alcohol, gasoline, acetone, benzene, dimethyl sulfide
Combustible liquid	Any liquid having a flash point at or above 100° and below 200° F as determined by tests listed in 49 CFR 173.115(d). Exceptions are listed in 49 CFR 173.115(b).	Ink, methyl amyl ketone, fuel oil
Flammable solid	Any solid material, other than an explosive, liable to cause fires through friction or retained heat from manufacturing or processing, or which can be ignited, readily creating a serious transportation hazard because it burns vigorously and persistently (49 CFR 173.150).	Nitrocellulose (film), phosphorus, charcoal
Oxidizer	A substance such as chlorate, permanganate, inorganic peroxide, or a nitrate that yields oxygen readily to stimulate the combustion of organic matter (49 CFR 173.151).	Potassium bromate, hydrogen peroxide solution, chromic acid
Organic peroxide	An organic compound containing the bivalent -0-0- structure and that can be considered a derivative of hydrogen peroxide where one or more of the hydrogen atoms have been replaced by organic radicals. Exceptions are listed in 49 CFR 173.151(a).	Urea peroxide, benzoyl peroxide
Corrosive	Liquid or solid that causes visible destruction or irreversible alterations in human skin tissue at the site of contact. Liquids that severely corrode steel are included (49 CFR 173.240(a)).	Bromine, soda lime, hydrochloric acid, sodium hydroxide solution
Flammable gas	A compressed gas, as defined in 49 CFR 173.300(a), that meets certain flammability requirements (49 CFR 173.300(b)).	Butadiene, engine starting fluid, hydrogen, liquefied petroleum gas
Nonflammable gas	A compressed gas other than a flammable gas.	Chlorine, xenon, neon, anhydrous ammonia

Appendix A (continued)

Hazard class	Definition	Examples
Irritating material	A liquid or solid substance which, on contact with fire or when exposed to air, gives off dangerous or intensely irritating fumes. Poison A materials excluded (49 CFR 173.381).	Tear gas, monochloroacetone
Poison A	Extremely dangerous poison gases or liquids belong to this class. Very small amounts of these gases or vapors of these liquids, mixed with air, are dangerous to life (49 CFR 173.326).	Hydrocyanic acid, bromoacetone, nitric oxide, phosgene
Poison B	Substances, liquids, or solids (including pastes and semisolids), other than Poison A or irritating materials, that are known to be toxic to humans. In the absence of adequate data on human toxicity, materials are presumed to be toxic to humans if they are toxic to laboratory animals exposed under specified conditions (49 CFR 173.343).	Phenol, nitroaniline, parathion, cyanide, mercury-based pesticides, disinfectants
Etiologic agents	A viable microorganism, or its toxin, that causes or may cause human disease. These materials are limited to agents listed by the Department of Health and Human Services (49 CFR 173.386, 42 CFR 72.3).	Vibrio cholerae, clostridium botulinum, polio virus, salmonella, all serotypes
Radioactive material	A material that spontaneously emits ionizing radiation having a specific activity greater than 0.002 microcurie per gram (uCi/g). Further classifications are made within this category according to levels of radioactivity (49 CFR 173, subpart I).	Thorium nitrate, uranium hexafluoride
Explosive	Any chemical compound, mixture, or device, the primary or common purpose of which is to function by explosion, unless such compound, mixture, or device is otherwise classified (49 CFR 173.50).	
	Explosives are divided into three subclasses:	
	Class A explosives are detonating explosives (49 CFR 173.53);	Jet thrust unit, explosive booster

Appendix A (continued)

Hazard class	Definition	Examples
Explosive (continued)	Class B explosives generally function by rapid combustion rather than by detonation (49 CFR 173.88); and	Torpedo, propellant explosive
	Class C explosives are manufactured articles, such as small arms ammunition, that contain restricted quantities of Class A and/or Class B explosives, and certain types of fireworks (49 CFR 173.100).	Toy caps, trick matches, signal flare, fireworks
Blasting agent	A material designed for blasting but so insensitive that there is very little probability of ignition during transport (49 CFR 173.114(a)).	Blasting cap
ORM (Other Regulated Materials)	Any material that does not meet the definition of the other hazard classes. ORMs are divided into five substances:	
	ORM-A is a material that has an anesthetic, irritating, noxious, toxic, or other similar property and can cause extreme annoyance or discomfort to passengers and crew in the event of leakage during transportation (49 CFR 173.500(a)(1)).	Trichloroethylene, carbon tetrachloride, ethylene dibromide, chloroform
	ORM-B is a material capable of causing significant damage to a transport vehicle or vessel if leaked. This class includes materials that may be corrosive to aluminum (49 CFR 173.500(a)(2)).	Calcium oxide, ferric chloride, potassium fluoride
	ORM-C is a material that has other inherent characteristics not described as an ORM-A or ORM-B, but which make it unsuitable for shipment unless properly identified and prepared for transportation. Each ORM-C material is specifically named in the Hazardous Materials Table in 49 CFR 172.101 (49 CFR 173.500(a)(3)).	Castor beans, cotton, inflatable life rafts
	ORM-D is a material such as a consumer commodity which, although otherwise subject to regulation, presents a limited hazard during transportation because of its form, quantity, and packaging (49 CFR 173.500(a)(4)).	Consumer commodity not otherwise specified, such as nail polish, small arms ammunition

Appendix A (continued)

Hazard class	Definition	Examples
ORM (continued)	ORM-E is a material that is not included in any other hazard class but is subject to the requirements of this subchapter. Materials in this class include hazardous wastes and hazardous substances (49 CFR 173.500(a)(5)).	Kepone, lead iodide, heptachlor, polychlorinated biphenyls

Source: 49 CFR 172.101 and 173 as cited in OTA 1986.

APPENDIX B

Statistical Analysis of the Transportation-Related Releases of Chemical Substances

B.1 Introduction

This appendix describes an analysis of historical data on transportation-related releases of chemical substances. The data used in the analysis are part of the HAZMAT data base operated by the U.S. Department of Transportation. A complete tape of the data in the HAZMAT data base was obtained from DOT in August 1986, and the data were studied using the Statistical Analysis System (SAS) on the EPA mainframe computer.

The purpose of this analysis was to determine whether the physical and chemical properties of a given substance can be correlated to the quantity of that substance released during domestic transportation. It had been ascertained in another study of the HAZMAT data base by ICF (1984) that the accident rate (number of accidents per mile) for trucks carrying chemicals is independent of the type of cargo. Also, because the HAZMAT data concern histories of releases only--not general transportation data--no information is available from HAZMAT on the probability of a release for a given accident. Therefore, this study focused on the quantity of substance released during a given release. Specifically, the percent of shipment released and the percent of container released were calculated for different groups of substances.

The percent of shipment released (SHIPREL) and the percent of container released (CONTREL) were calculated using data from various fields of the HAZMAT data base as follows:

Percent of shipment released (SHIPREL) = (B-1)

$$\frac{\text{Quantity Released (RQUAN)}}{\text{Number of the Shipment's Containers (NSH1)} \times \text{Container's Capacity (CAP1)}} \times 100$$

Percent of Container Released (CONTREL) = (B-2)

$$\frac{\text{Quantity Released (RQUAN)}}{\text{Number of Failed Containers (NFL1)} \times \text{Container's Capacity (CAP1)}} \times 100.$$

One problem encountered in performing these calculations was that some of the HAZMAT data records used different units to report the quantity released (RQUAN) and the container's capacity (CAP1). Therefore, units had to be converted to the smallest possible unit within the measuring scale available for each DOT hazard class. Summary statistics (mean, standard deviation, median, 95th percentile, and 95 percent confidence limit), frequency tables, frequency histograms, and analysis of variance (ANOVA) were prepared for the SHIPREL and CONTREL. A series of ANOVAs was performed on each of the SHIPREL and CONTREL to determine sources of variation within the sample. When a source of variation proved to be significant, the SHIPREL and CONTREL for that sample were analyzed separately and summary statistics were determined. A Chi-Square test was performed on the frequency tables of the SHIPREL and CONTREL. The Chi-Square test for the homogeneity of the distribution of each percentage among the levels of the factors was considered in the analysis. The correlation between the quantity released and the shipment size is presented in this appendix. The shipment size is calculated as the number of containers per shipment (NSHI) x the container's capacity (CAPI).

An overview of the HAZMAT data base is presented in Section B.2. A discussion of the analysis of variance (ANOVA) method is found in Section B.3.1 and a review of the Chi-Square method is given in Section B.3.2. Section B.4 defines the factors considered in the analysis and their levels. Analysis of variance and summary statistics results are provided in Section B.5 for the percent of shipment released. Similarly, analysis of variance and summary statistics results for the percent of container released are presented in Section B.6. Frequency distribution and the Chi-Square test of homogeneity results are provided in Section B.7 for the percent of shipment released and in Section B.8 for the percent of container released. Correlation coefficients between the quantity released and the shipment size are found in Section B.9. Section B.10 discusses the conclusions derived from these analyses.

B.2 The HAZMAT Data Base

The primary data source used in estimating predictive release factors for each hazard class was the DOT's Hazardous Material Incident File (HAZMAT). This data base is maintained on the DOT's Digital Electronic Corporation DEC10 computer in Cambridge, Massachusetts. As of 1986, HAZMAT contained 151,067 records* documenting inadvertent releases of hazardous materials. The data in HAZMAT are provided by carriers on the Hazardous Materials Incident Report (form DOT F 5800.1) whenever there is an unintentional hazardous substance release. The types of data contained in HAZMAT are listed in Table B-1.

The data in the HAZMAT data base were manipulated using the Statistical Analysis System (SAS) on the EPA mainframe computer. This was done in order to calculate the relative frequency distributions of the percent of shipment released and the percent of container contents released for a given hazard class carried by each mode of transportation.

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* Phone conversation with Sadie Willoughby, USDOT, September 25, 1986.

Table B-1. Types of Data Contained in the HAZMAT Data Base

Report number
Multiple code
Date of incident
Incident city
Incident state
Mode
Carrier's ID
Carrier's name
Shipper's ID
Shipper's name
Origin city
Origin state
Destination city
Destination state
Major injuries
Minor injuries
Deaths
Damages

Damage code (1 = Damage unknown, 0 = Damage as shown)
Quantity released
Units of quantity released
Commodity code
Commodity name
Commodity class
Failure code 1 Container 1
Failure code 2 Container 1
Container 1
Capacity of Container 1
Capacity units Container 1
Number of failed containers
Number of containers in shipment
Gauge of Container 1
Manufacturer's ID
Tank car ID No.

Label or placard
Registration exemption no.
Inspection date
General cause of incident
Result of release
Miscellaneous info 1
Miscellaneous info 2
Container 2 code
Date added to data base
Date of last change

Source: DOT Research and Special Programs Administration, Washington, D.C. No date.

The types of HAZMAT data included in this statistical analysis are presented in Table B-2. Four DOT hazard classes were excluded from the statistical analysis. They were (1) blasting agents, (2) radioactive materials, (3) explosives (A, B, and C), and (4) etiological agents.

The modes of transportation covered in HAZMAT are air, rail, water, and highway. Note that the highway mode includes the following: (1) highway (for hire), (2) highway (private), (3) freight forwarder, and (4) other.

This analysis included only those HAZMAT records designated as multiple code "A," which indicated that the release incident involved a single shipper, commodity, container type and size, and container manufacturer.

Failure codes in HAZMAT indicate how a substance was released (e.g., dropped in handling, hose burst, or loading/unloading). Excluded from the analysis were failure codes that did not describe incidents directly related to en route transport.

Because the majority of releases in HAZMAT involve liquids,* it was assumed that all releases were liquid unless another physical state was specified for a particular hazard class (e.g., flammable solid, compressed flammable gas).

B.3 Description of Statistical Methods Used in This Analysis

This section describes the statistical techniques used in this analysis and the meaning of some of the terms used to describe the statistical parameters. Section B.3.1 describes the analysis of variance (ANOVA) technique, Section B.3.2 discusses the Chi-Square test for homogeneity, and Section B.3.3 contains the correlation analysis.

B.3.1 Analysis of Variance (ANOVA)

Analysis of variance (ANOVA) is a technique whereby the total variation present in a set of data is partitioned into several components. Associated with each of these components is a specific source of variation, so that in the analysis, it is possible to ascertain the magnitude of each source's contribution and the total variation. The components of the total variation in a set of data, and other related statistics, are usually displayed in an analysis table as shown in Table B-3. The first column in Table B-3 identifies the two sources of variation investigated. The first source of variation (called the model source) refers to the name of the investigated factor in the model (e.g.,

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* Telephone contact with Kevin Coburn, USDOT, September 24, 1986.

Table B-2. HAZMAT Data Used in the Statistical Analysis

Multiple code
Mode
Quantity released
Commodity code
Commodity name
Commodity class
Failure code
Capacity of container
Capacity units of container
Number of failed containers
Number of containers in shipment

Table B-3. Analysis of Variance Results for the Percent of Shipment Released (SHIPREL) by DOT Hazard Class

```
                              ANALYSIS OF VARIANCE PROCEDURE
                                 CLASS LEVEL INFORMATION
                          Class       Levels      Values
                          Class         3         Gas Liquid Solid

                          NUMBER OF OBSERVATIONS IN DATA SET  =  55,296

DEPENDENT VARIABLE:  SHIPREL
-------------------------------------------------------------------------------------------------
Source              DF      Sum of squares     Mean square     F-value    PR > F    R-square    C.V.
-------------------------------------------------------------------------------------------------
Model                2      32055.25575082   16027.6278754      27.83     0.0001    0.00158    213.1273

Error            52554   30267236.58747520     575.92647069               Root Mse            SHIPREL Mean

Corrected Total  52556   30299291.84316600                                23.99846684          11.26015697

Source              DF      ANOVA SS           F-value      PR > F

Class                2      32055.25575082      27.83       0.0001
-------------------------------------------------------------------------------------------------
```

Table B-3. Analysis of Variance Results for the Percent of Shipment Released (SHIPREL) by DOT Hazard Class

ANALYSIS OF VARIANCE PROCEDURE
CLASS LEVEL INFORMATION

Class	Levels	Values
Class	3	Gas Liquid Solid

NUMBER OF OBSERVATIONS IN DATA SET = 55,296

DEPENDENT VARIABLE: SHIPREL

Source	DF	Sum of squares	Mean square	F-value	PR > F	R-square	C.V.
Model	2	32055.25575082	16027.6278754	27.83	0.0001	0.00158	213.1273
Error	52554	30267236.58747520	575.92647069		Root Mse		SHIPREL Mean
Corrected Total	52556	30299291.84316600			23.99846684		11.26015697

Source	DF	ANOVA SS	F-value	PR > F
Class	2	32055.25575082	27.83	0.J001

mode of transportation). The second source of variation is called the error or residual, which is the part of the total variation caused by other factors not investigated.

For each source of variation, the degrees of freedom (DF), sum of squares, mean squares, F-value, and significance of the F-value (or the P-value) are calculated (see Table B-3).

> The number of degrees of freedom for the model source is equal to the number of independent comparisons between the averages of the levels of that factor and the grand average of the factor. Therefore, the degrees of freedom of a model source equal the number of levels of that source minus one (e.g., for physical states, the number of levels is limited to three, that is, gas, liquid, and solid).
>
> Sum of squares of the model source is the sum of the square of the mean deviations of the source (e.g., chemical classes) from the grand mean of the data. Therefore, the sum of squares of the model source tends to be large if the individual means vary considerably around the grand mean. The corrected total sum of squares (SST) is then equal to the sum of the squares of the data from the grand mean. The error sum of squares (SSE) is the difference between the total sum of squares and the model sum of squares.
>
> The mean squares are obtained by dividing the sums of squares by the corresponding degrees of freedom. Squares can be considered as the average of the sum of squares.
>
> The F-value of the model is obtained by dividing the model mean square by the error mean square. This ratio follows a probability distribution known as the F-distribution.
>
> The P-value corresponds to the area to the right of the F-value under the probability curve of the F-distribution. Therefore, the P-value of a source of variation is the probability that the contribution of that source to the total variation is not significant. Accordingly, if the P-value is small, there is a high probability (1-P) that the contribution is significant. The P-value is considered small if it does not exceed a pre-assigned level known as the significance level. The significance level assigned in this study is 0.10.

The relative frequency histograms presented in Figures B-1 through B-7 are skewed and U-shaped; while under the assumption of normality of

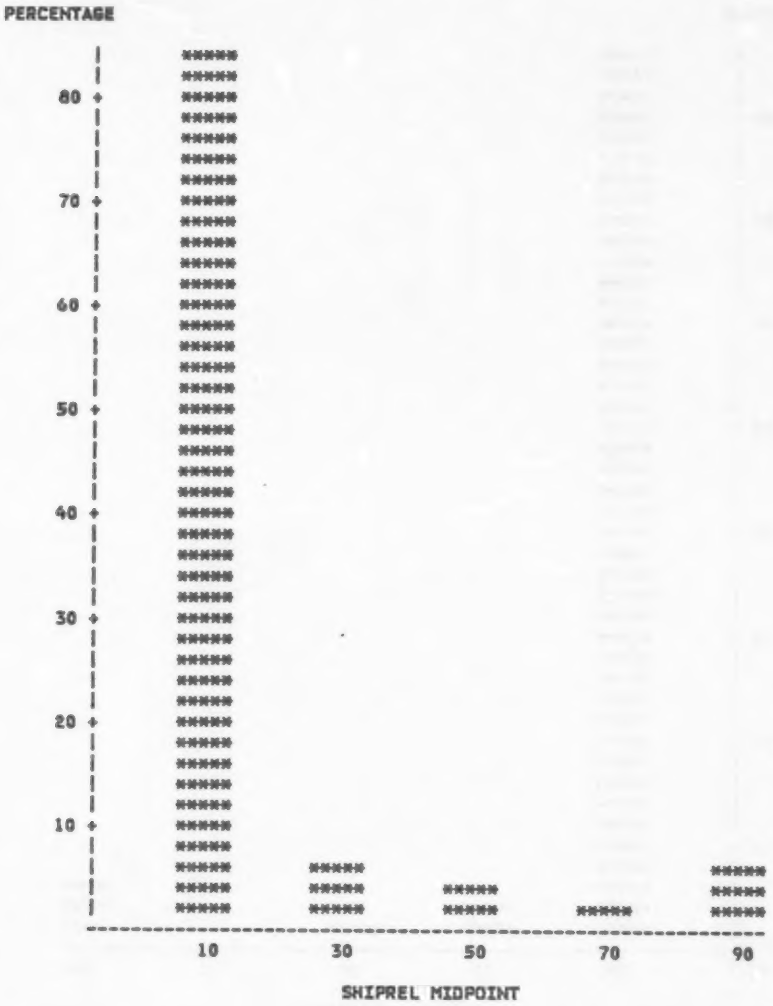

Figure B-1. Percentage bar chart for the frequency distribution of the percent of shipment released for liquids.

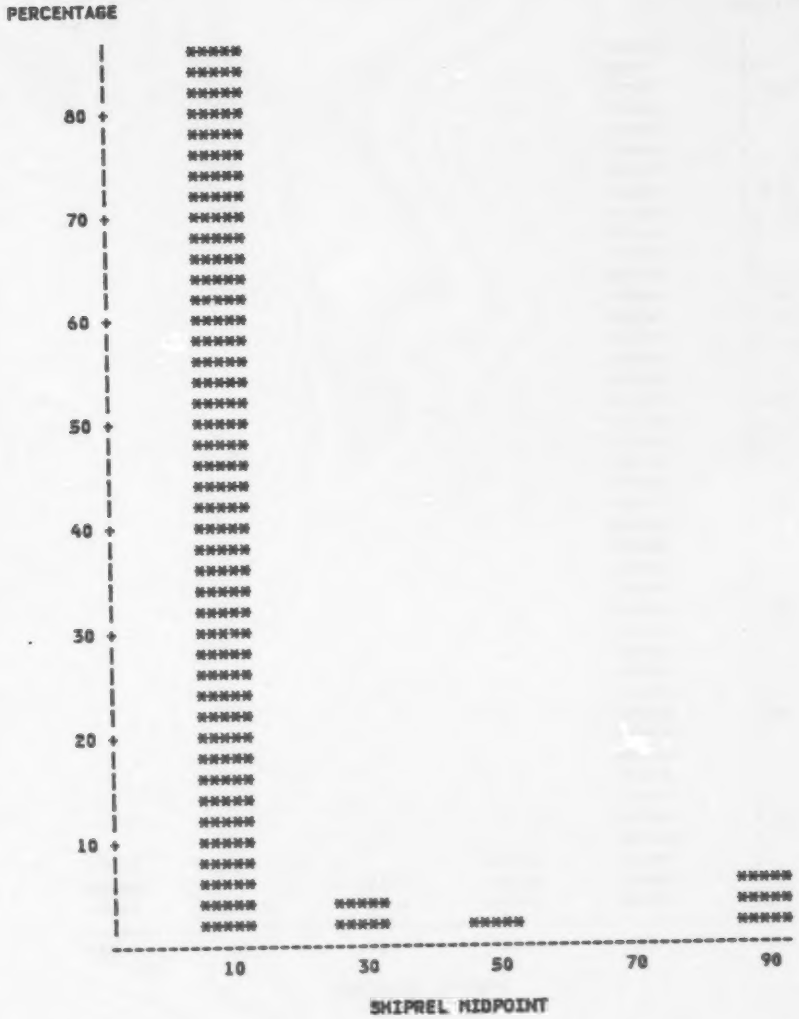

Figure B-2. Percentage bar chart for the frequency distribution of the percent of shipment released for solids.

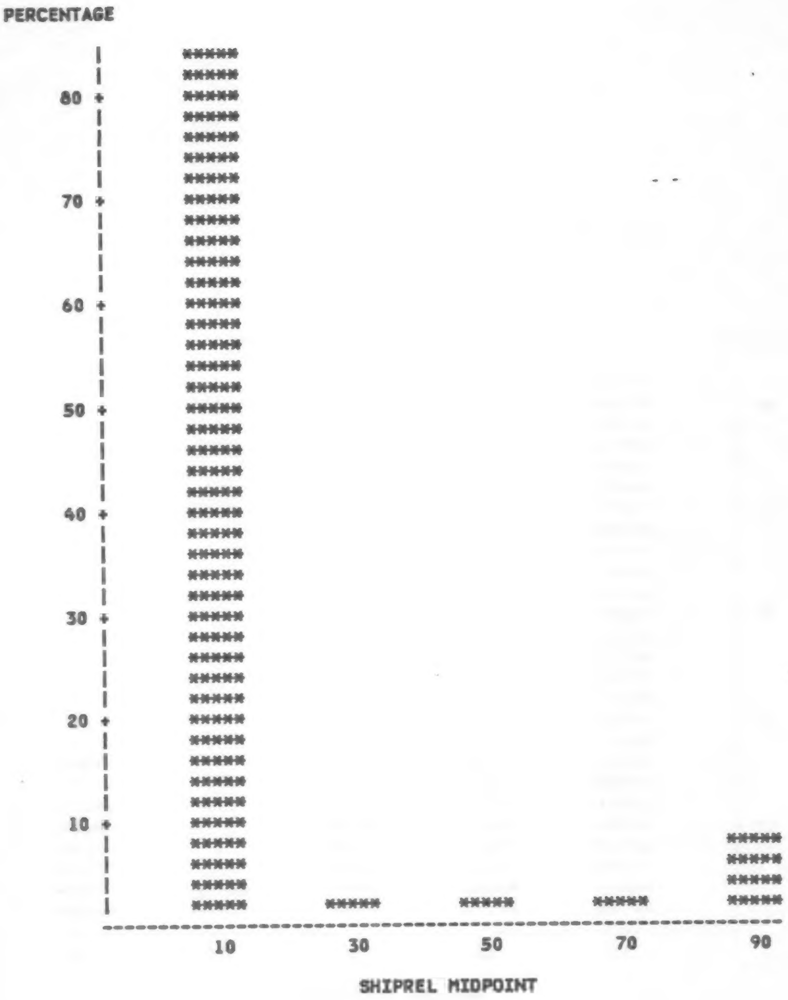

Figure B-3. Percentage bar chart for the frequency distribution of the percent of shipment released for gases.

```
PERCENTAGE

      |       *****
   50 +       *****
      |       *****
      |       *****
      |       *****
      |       *****
   40 +       *****
      |       *****
      |       *****
      |       *****
      |       *****
   30 +       *****
      |       *****
      |       *****
      |       *****
      |       *****
   20 +       *****
      |       *****
      |       *****       *****                                   *****
      |       *****       *****                                   *****
      |       *****       *****       *****                       *****
   10 +       *****       *****       *****                       *****
      |       *****       *****       *****                       *****
      |       *****       *****       *****                       *****
      |       *****       *****       *****       *****           *****
      |       *****       *****       *****       *****           *****
      --------------------------------------------------------------
               10          30          50          70          90

                            SHIPREL MIDPOINT
```

Figure B-4. Percentage bar chart for the frequency distribution of the percent of shipment released for the air mode of transportation.

```
PERCENTAGE

       I       *****
       I       *****
    80 +       *****
       I       *****
       I       *****
       I       *****
       I       *****
    70 +       *****
       I       *****
       I       *****
       I       *****
       I       *****
    60 +       *****
       I       *****
       I       *****
       I       *****
       I       *****
    50 +       *****
       I       *****
       I       *****
       I       *****
       I       *****
    40 +       *****
       I       *****
       I       *****
       I       *****
       I       *****
    30 +       *****
       I       *****
       I       *****
       I       *****
       I       *****
    20 +       *****
       I       *****
       I       *****
       I       *****
       I       *****
    10 +       *****
       I       *****
       I       *****       *****                               *****
       I       *****       *****                               *****
       I       *****       *****                   *****       *****
       --------------------------------------------------------------
                10          30          50          70          90

                           SHIPREL MIDPOINT
```

Figure B-5. Percentage bar chart for the frequency distribution of the percent of shipment released for the water mode of transportation.

```
PERCENTAGE

       I      *****
   90 +      *****
       I      *****
       I      *****
       I      *****
       I      *****
   80 +      *****
       I      *****
       I      *****
       I      *****
       I      *****
   70 +      *****
       I      *****
       I      *****
       I      *****
       I      *****
   60 +      *****
       I      *****
       I      *****
       I      *****
       I      *****
   50 +      *****
       I      *****
       I      *****
       I      *****
       I      *****
   40 +      *****
       I      *****
       I      *****
       I      *****
       I      *****
   30 +      *****
       I      *****
       I      *****
       I      *****
       I      *****
   20 +      *****
       I      *****
       I      *****
       I      *****
       I      *****
   10 +      *****
       I      *****
       I      *****
       I      *****                                   *****
       I      *****     *****     *****                    *****
       -----------------------------------------------------
               10        30        50        70        90

                          SHIPREL MIDPOINT
```

Figure B-6. Percentage bar chart for the frequency distribution of the percent of shipment released for the rail mode of transportation.

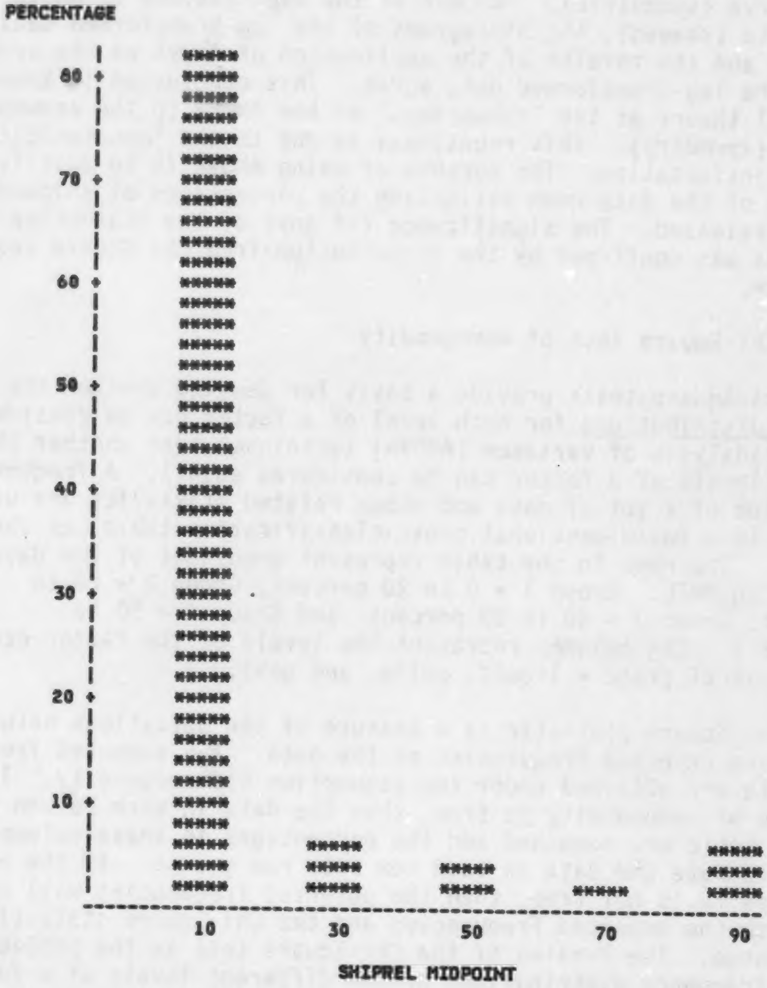

Figure B-7. Percentage bar chart for the frequency distribution of the percent of shipment released for the highway mode of transportation.

the data, these histograms would be similar in shape to that of a "bell shaped" curve (symmetric). In most of the applications of ANOVA to similar data (skewed), the histograms of the log-transformed data are symmetric, and the results of the application of ANOVA on the original data and the log-transformed data agree. This conclusion is known in statistical theory as the "robustness" of the ANOVA to the assumption of normality (symmetry). This robustness is due to the "monotonicity" of the log-transformation. The purpose of using ANOVA is to justify the nonpooling of the data when estimating the percentages of shipment and container released. The significance (if any) of the statistical differences was confirmed by the distribution-free Chi-Square test of homogeneity.

B.3.2 Chi-Square Test of Homogeneity

The Chi-Square tests provide a basis for judging whether the frequency distributions for each level of a factor can be considered to be equal (analysis of variance [ANOVA] techniques test whether the means for these levels of a factor can be considered equal). A frequency distribution of a set of data and other related statistics are usually displayed in a two-dimensional cross-classification table, as shown in Table B-4. The rows in the table represent groupings of the data (e.g., groups of SHIPREL: Group 1 = 0 to 20 percent, Group 2 = 20 to 40 percent, Group 3 = 40 to 80 percent, and Group 4 = 80 to 100 percent). The columns represent the levels of the factor considered (e.g., physical state = liquid, solid, and gas).

The Chi-Square statistic is a measure of the deviations between the observed and expected frequencies of the data. The expected frequencies of the data are obtained under the assumption of homogeneity. If the assumption of homogeneity is true, then the data in each column of the frequency table are combined and the percentages in these columns are used to separate the data in each row into row groups. If the assumption of homogeneity is not true, then the observed frequencies will tend to depart from the expected frequencies and the Chi-Square statistic value will be large. The P-value of the Chi-Square test is the probability that the frequency distributions of the different levels of a factor are equal. Accordingly, if the P-value is small (<.10), there is a high probability (>.90) that the frequency distributions are not equal.

B.4 Other Factors Considered in the Analysis

In order to investigate the possible significant contributions in the total variation of the percent of shipment released and the variation of the percent of container released, the following variables were used:

Table B-4. The Frequency Distribution and Chi-Square Test of Homogeneity Results for the Percent of Shipment Released (SHIPREL) by Physical State

Class Frequency percent (row PCT)	Group 1	 2	 3	 4	 Total
Gas	1707	47	45	26	1825
	3.25	0.09	0.09	0.05	3.47
	93.53	2.58	2.47	1.42	
Liquid	41060	2470	1533	512	45575
	78.07	4.70	2.91	0.97	86.65
	90.09	5.42	3.36	1.12	
Solid	4811	223	131	30	5195
	9.15	0.42	0.25	0.06	9.88
	92.61	4.29	2.52	0.58	
Total	47578	2740	1709	568	52595
	90.46	5.21	3.25	1.08	100.00

Frequency Missing = 2,701.

Statistics for Table of Class by Group

Statistic	Degrees of freedom (DF)	Value	Probability (P-value)
Chi-Square	6	70.488	0.000
Likelihood Ratio Chi-Square	6	79.868	0.000
Mantel-Haenszel Chi-Square	1	11.821	0.001
PHI		0.037	
Contingency Coefficient		0.037	
Cramer's V		0.026	

Effective Sample Size = 52,595.

(1) DOT hazard class (or commodity class), (2) physical state (i.e., solid, liquid, or gaseous), and (3) mode of transportation.

B.4.1 DOT Hazard Class

Differences among DOT hazard classes of chemicals are viewed as a possible factor for variation in the HAZMAT data. Three physical states are considered: (1) liquid, (2) solid, and (3) gas. Data on physical state are not provided in individual incident records contained in the HAZMAT data base. Therefore, data records were classified according to the type of physical state described for each hazard class in the HAZMAT data base. The following classification is used in the statistical analysis:

Physical state	Commodity class (CMCL)*	DOT hazard class
Liquid	2	Other Regulated Material Class A
	4	Other Regulated Material Class B
	6	Other Regulated Material Class C
	8	Other Regulated Material Class D
	9	Other Regulated Material Class E
	20	Combustible Liquid
	25	Flammable Liquid
	95	Corrosive Material
Solid	10	Organic Peroxide
	30	Flammable Solid
	35	Oxidizer
	60	Poison, Class B
Gas	45	Nonflammable Compressed Gas
	50	Flammable Compressed Gas
	55	Poison, Class A
	65	Irritating Material

Some DOT hazard classes include materials of more than one physical state. For example Poisons, Class B, includes both liquids and solids, and Poisons, Class A, includes both liquids and gases. In these cases, the physical state most representative of the hazard class was selected. Alternative classification by physical state was investigated, and the

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* Commodity class (CMCL) is a numerical code corresponding to a DOT hazard class. Commodity class is used as a field in the DOT HAZMAT data base.

ANOVA results and Chi-Square results for alternative physical state classification were not significantly different from those results for the physical state selected.

B.4.2 Physical State

Differences among physical states of the chemicals for which HAZMAT release records are available are considered a possible factor for variation in the HAZMAT data. The physical states assigned to each commodity class (i.e., DOT hazard class) are listed above in Section B.4.1.

B.4.3 Mode of Transportation

Differences among modes of transportation are considered another possible reason for variation in the HAZMAT data. The modes of transportation included in this study are air, barge (waterborne), rail, and truck.

B.5 Analysis of Variance and Summary Statistics for the Percent of Shipment Released

The first ANOVA was performed on the SHIPREL data to investigate the significance of the DOT hazard class as a source of variation in the HAZMAT data. The results of this ANOVA were presented in Table B-3; they show that the DOT hazard class has a significant effect on the variations in the percent of shipment released (P-value < 0.10). This means that the mean percent of shipment released (SHIPREL) is significantly different for DOT hazard classes. Therefore, these data for shipment releases may not be pooled or combined for further analysis.

The second ANOVA was performed on the percent of shipment released data to investigate the significance of the mode of transportation as a source of variation. These results are presented in Table B-5; they indicate that mode of transportation has a significant effect on the variation in SHIPREL (P-value < .10). The significance of the mode of transportation implied that the SHIPREL data for different modes of transportation should not be combined for further analysis.

Summary statistics (number of data records used; mean and standard deviation, 95 percent upper confidence limit, median, and 90th percentile) for the SHIPREL are presented in Table B-6 (by physical state), Table B-7 (by mode of transportation), and Table B-8 (by physical state and mode of transportation).

The overall average (that is, for all DOT hazard classes and all modes of transportation) of the percent of shipment released (SHIPREL) is

Table B-5. Analysis of Variance Results for the Percent of Shipment Released (SHIPREL) by the Mode of Transportation

ANALYSIS OF VARIANCE PROCEDURE
CLASS LEVEL INFORMATION

Class	Levels	Values
Mode	4	Air, Water, Rail, Truck

NUMBER OF OBSERVATIONS IN DATA SET = 55,296

DEPENDENT VARIABLE: SHIPREL

Source	DF	Sum of squares	Mean square	F-value	PR > F	R-square	C.V.
Model	3	139692.2980544	46564.09936721	81.14	0.0001	0.004610	212.7500
Error	52553	30159599.54508060	573.88920794		Root Mse		SHIPREL Mean
Corrected Total	52556	30299291.84316600			23.95598480		11.26015697

Source	DF	ANOVA SS	F-value	PR > F
Class	3	139692.29808544	81.14	0.0001

Table B-6. Summary Statistics for the Percent of Shipment Released (SHIPREL) for Each Physical State (Gas, Liquid, Solid)

Physical state	Number of data records (N)	Mean	Standard deviation	Upper 90% confidence limit	Median	90th Percentile
Gas	1,697	13.2099	29.4428	14.3820	0.03333	70.1667
Liquid	45,904	11.6824	24.2284	11.8679	1.25000	40.0000
Solid	5,484	9.3291	22.3211	9.8234	0.62500	25.0000
All		11.26				

Table B-7. Summary Statistics for the Percent of Shipment Released (SHIPREL) by the Mode of Transportation

Physical state	Number of data records (N)	Mean	Standard deviation	Upper 90% confidence limit	Median	90th Percentile
Air	594	16.7608	28.4926	18.6781	1.96154	52.8977
Barge	110	10.8142	24.7357	14.6820	0.54710	33.2885
Rail	6,130	7.0591	22.7003	7.5346	0.01238	10.0000
Truck	46,251	12.0090	24.3063	12.1944	1.49254	40.0000
All		11.26				

Table B-8. Summary Statistics for the Percent of Shipment Released (SHIPREL) by the Physical State and Mode of Transportation

Physical state	Mode of transportation	Number of data records (N)	Mean	Standard deviation	Upper 90% confidence limit	Median	90th Percentile
Gas	Air	9	57.7914	46.8759	83.4169	83.3333	100.000
Gas	Barge	6	39.9056	47.3122	71.5825	16.8950	100.000
Gas	Rail	1,043	5.0815	20.4939	6.1222	0.0042	1.634
Gas	Truck	639	25.5988	35.7337	27.9171	4.7225	100.000
Liquid	Air	538	16.4369	27.9920	18.4161	1.9615	50.000
Liquid	Barge	83	10.7439	24.2523	15.1097	0.5594	39.739
Liquid	Rail	4,616	6.9636	22.4186	7.5047	0.0152	9.982
Liquid	Truck	40,667	12.1571	24.3102	12.3548	1.6667	41.667
Solid	Air	47	12.6114	24.2501	18.4125	0.7000	50.000
Solid	Barge	21	2.7800	6.4653	5.0938	0.3030	14.123
Solid	Rail	471	12.3741	28.5742	14.5333	0.2353	49.999
Solid	Truck	4,945	9.0357	21.6341	9.5402	0.6494	25.000

11.26 percent. This means that when an accident involving a release occurs, the average loss of cargo will be 11 percent.

The results displayed in Table B-6 indicate that the SHIPREL for gaseous chemicals had a higher mean and the SHIPREL for solid chemicals had a lower mean than the overall mean.

It can be seen from the results presented in Table B-7 that HAZMAT records for air transportation had a higher average percent of shipment releases, and rail transportation had a lower average percent shipment releases than the overall mean. The results also show that the averages for barge and truck transportation are significantly different from the overall mean. The results in Table B-7 reveal statistically significant differences among the means of percent of shipment released (SHIPREL) for the modes of transportation for each physical state.

The means of the percent of shipment released (SHIPREL) presented in Tables B-6, B-7, and B-8 can be used as estimates or predictions for the average percent of shipment released. Upper confidence limits are obtained for the average of percent of shipment released at the 95 percent confidence level. The relative frequency histograms presented in Figures B-1 through B-7 are skewed and U-shaped. For skewed distributions,the sample mean tends to overestimate the central tendency of the distribution. The sample median (the value that 50 percent of the data are less than) is a preferred estimate of the central tendency of these distributions. The median and the 95th percentile (the value that 95 percent of the data are less than) are presented in Tables B-6, B-7, and B-8. The 95 percent upper confidence limit and the 95th percentile represent very conservative estimates of the percentage of shipment and container releases. The 95 percent upper confidence limit is computed as the sample mean (1.64 x standard error of the mean). The standard error of the mean equals the standard deviation divided by the square root of the sample size. This computation is justified by the "Central Limit Theorem" for large sample sizes ($\geq$30). For small samples (<30), the confidence limit is not justified and the 95th percentile represents a nonparametric conservative estimate.

The third analysis performed was a sequence of ANOVAs of the percent of shipment released (SHIPREL) to investigate the signficance of the physical states as a source of variation within each DOT hazard class. The results listed in Tables B-9, B-10, and B-11 show that significant differences exist among hazard classes having the same assigned physical state (P-values < .10). Summary statistics for the percent of shipment released (SHIPREL) classified by DOT hazard class and physical state are cited in Table B-12.

Table B-9. Analysis of Variance Results for the Percent of Shipment Released (SHIPREL) by the Physical State (Liquid)

CLASS = LIQUID
ANALYSIS OF VARIANCE PROCEDURE
CLASS LEVEL INFORMATION

Class	Levels	Values
CMCL	8	2 4 6 8 9 20 25 95

NUMBER OF OBSERVATIONS IN DATA SET = 47,892

DEPENDENT VARIABLE: SHIPREL

Source	DF	Sum of squares	Mean square	F-value	PR > F	R-square	C.V.
Model	7	193183.58907803	27597.69415400	48.30	0.0001	0.007381	208.7352
Error	45474	25987830.44570020	571.34253519		Root Mse		SHIPREL Mean
Corrected Total	45481	26174414.30417820			23.90277254		11.45124244

Source	DF	ANOVA SS	F-value	PR > F
Class	7	193183.85907803	48.30	0.0001

Table B-10. Analysis of Variance Results for the Percent of Shipment Released (SHIPREL) by the Physical State (Solid)

CLASS = SOLID
ANALYSIS OF VARIANCE PROCEDURE
CLASS LEVEL INFORMATION

Class	Levels	Values
CMCL	4	10 30 35 60

NUMBER OF OBSERVATIONS IN DATA SET = 5,429

DEPENDENT VARIABLE: SHIPREL

Source	DF	Sum of squares	Mean square	F-value	PR > F	R-square	C.V.
Model	3	19273.19854026	6424.39951342	13.18	0.0001	0.007282	242.5897
Error	5391	2627307.61581922	487.35609854		Root Mse		SHIPREL Mean
Corrected Total	5394	2646580.81435947			22.07602089		9.10014616

Source	DF	ANOVA SS	F-value	PR > F
Class	3	19273.19854026	13.18	0.0001

Table B-11. Analysis of Variance Results for the Percent of Shipment Released (SHIPREL) by the Physical State (Gas)

```
                              CLASS = GAS
                      ANALYSIS OF VARIANCE PROCEDURE
                         CLASS LEVEL INFORMATION
                    Class        Levels        Values
                    CMCL           4           45 50 55 65

                  NUMBER OF OBSERVATIONS IN DATA SET  =  1,975

DEPENDENT VARIABLE:  SHIPREL
_____________________________________________________________________________________________________

Source             DF       Sum of squares        Mean square      F-value      PR > F     R-square      C.V.
_____________________________________________________________________________________________________

Model                3         9565.52418973     3188.50804324     3.72          0.0111      0.006614     224.8106

Error             1676      1436675.94475854      857.20521764                 Root Mse                  SHIPREL Mean

Corrected Total   1679      1446241.46888827                                   29.27806718               13.02343614

Source            DF        ANOVA SS              F-value          PR > F

Class                3         9565.52412973        3.72           0.0111
_____________________________________________________________________________________________________
```

Table B-12. Summary Statistics for the Percent of Shipment Released (SHIPREL) by the Physical State and Hazard Class

Physical state	Hazard class	Number of data records (N)	Mean	Standard deviation	Upper 90% confidence limit	Median	90th Percentile
Gas	45	715	14.9162	31.4173	16.8431	0.0760	89.216
Gas	50	935	11.4638	27.3097	12.9285	0.0165	52.680
Gas	55	21	24.2708	39.3608	38.3572	1.6667	100.000
Gas	65	26	20.1427	34.1419	31.1238	2.7652	100.000
Liquid	2	335	23.7631	33.2710	26.7442	5.0000	100.000
Liquid	4	52	23.4281	33.4280	31.0305	4.3182	94.000
Liquid	6	27	32.7767	37.6030	44.6449	11.4286	100.000
Liquid	8	31	6.7674	14.8483	11.1410	1.4933	23.610
Liquid	9	213	8.1421	20.1145	10.4024	0.5195	32.000
Liquid	20	2407	16.5154	28.7261	17.4756	1.3043	66.690
Liquid	25	19670	9.9732	22.4397	10.2356	0.9091	32.727
Liquid	95	23169	12.4449	24.8456	12.7126	1.6667	43.804
Solid	10	349	9.8715	23.1605	11.9047	1.1111	25.000
Solid	30	452	6.1609	19.6327	7.6754	0.1230	12.100
Solid	35	1490	12.1130	25.3016	13.1880	1.0000	41.570
Solid	60	3193	8.4192	20.9371	9.0268	0.5882	25.000

The fourth analysis performed on a sequence of the percent of shipment released (SHIPREL) investigated the significance of the mode of transportation for each physical state. The P-values of the ANOVA results are shown in Table B-13 and indicate that mode of transportation is a significant factor for some combinations of physical state and commodity (hazard) class (uses with P-value < .10). Table B-14 presents summary statistics for the fraction of shipment released by commodity (hazard) class, physical state, and mode of transportation. It should be noted that a small number of data records were used for the computation of the summary statistics for some of the cases in Table B-14 (e.g., first line: physical state = gas, CMCL = 45, and mode = air). Results based on number of data records (N) less than ten are unreliable and should not be considered representative of the population from which they were drawn.

B.6 Analysis of Variance, Summary Statistics, and Confidence Limits for the Percent of Container Contents Released (CONTREL)

Four sequences of ANOVAs were performed on the percent of container contents released (CONTREL). The first ANOVA was performed to investigate the significance of the commodity class (DOT hazard class). The results are listed in Table B-15 and indicate that commodity class (DOT hazard class) is a significant factor. The second ANOVA was performed to investigate the significance of the mode of transportation. These results are contained in Table B-16 and indicate that mode of transportation is also a significant factor.

Summary statistics for the percent of container contents released are listed in Table B-17 (by physical state), Table B-18 (by mode of transportation), and Table B-19 (by physical state and mode of transportation). The overall average of the percent of container contents released is 30 percent. The results in Table B-17 show that the mean values for percent of container contents released for liquids and solids do not differ significantly from the overall mean. These results also demonstrate that chemicals shipped as a gas have a lower mean of percent of container contents released than does the overall mean. The results in Table B-18 show that the mean percent of container contents released for air, barge, and truck did not differ significantly from the overall mean, but that rail had a lower mean percent of container contents released than did the overall mean. The results in Table B-19 reveal that the mean percent of container contents released classified by mode of transportation and commodity class differs from the overall mean.

The third sequence of ANOVAs was performed to investigate the significance of the physical states within each commodity (DOT hazard) class. The results are listed in Tables B-20, B-21, and B-22 and show

Table B-13. Analysis of Variance Results for the Percent of Shipment Released (SHIPREL) by the Mode of Transportation for Each Physical State and Each Commodity Class

Physical state	Commodity class (CMCL)	DOT hazard class	P-value
Liquid	2	ORM-A	.5784
	4	ORM-B	.0001
	6	ORM-C	.7640
	8	ORM-D	.0048
	9	ORM-E	.6876
	20	Combustible Liquid	.0011
	25	Flammable Liquid	.0032
	95	Corrosive Material	.0001
Solid	10	Organic Peroxide	.7986
	30	Flammable Solid	.0930
	35	Oxidizer	.0001
	60	Poison B	.1061
Gas	45	Nonflammable/Compressed Gas	.0001
	50	Flammable Compressed Gas	.0001
	55	Poison A	.2624
	65	Irritating Material	.5625

Table B-14. Summary Statistics for the Percent of Shipment Released (SHIPREL) by the Commodity Class (DOT Hazard Class), Physical State, and Mode of Transportation

Physical state	CMCL	Mode of transportation	Number of data records (N)	Mean	Standard deviation	Upper 90% confidence limit	Median	90th Percentile
Gas	45	Air	3	100.000	0.0000	100.000	100.000	100.000
Gas	45	Barge	4	34.804	44.3530	71.174	16.895	100.000
Gas	45	Rail	431	5.276	21.0567	6.939	0.009	0.992
Gas	45	Truck	277	28.708	37.6940	32.422	6.857	100.000
Gas	50	Air	6	36.687	43.7304	65.966	16.192	100.000
Gas	50	Barge	1	100.000	----	---	100.000	100.000
Gas	50	Rail	609	4.968	20.1511	6.307	0.003	1.861
Gas	50	Truck	319	23.113	33.6233	26.200	4.000	86.364
Gas	55	Rail	3	0.169	0.2869	0.440	0.003	0.500
Gas	55	Truck	18	28.288	41.2682	44.240	5.435	100.000
Gas	65	Air	0	---	---	---	---	---
Gas	65	Barge	1	0.216	---	---	0.216	0.216
Gas	65	Truck	25	20.940	34.5982	32.288	3.030	100.000
Liquid	2	Air	38	26.487	33.5358	35.409	12.500	91.000
Liquid	2	Rail	18	29.207	43.3406	45.960	0.656	100.000
Liquid	2	Truck	279	23.041	32.5874	26.240	5.000	100.000
Liquid	4	Air	17	49.863	41.1131	66.216	33.333	100.000
Liquid	4	Rail	3	2.402	4.0504	6.237	0.124	7.078
Liquid	4	Truck	32	11.356	19.7094	17.070	2.947	47.000
Liquid	6	Rail	2	24.873	35.1183	65.598	24.873	49.705
Liquid	6	Truck	25	33.409	38.4032	46.005	11.429	100.000
Liquid	8	Air	4	15.534	23.2395	34.590	5.373	50.000
Liquid	8	Truck	27	5.469	13.3604	9.685	1.250	12.121
Liquid	9	Barge	1	0.014	---	---	0.014	0.014
Liquid	9	Rail	21	11.383	23.7671	19.889	0.519	36.922
Liquid	9	Truck	191	7.828	19.7579	10.173	0.519	26.818
Liquid	20	Air	6	17.486	15.3460	27.760	18.750	40.000
Liquid	20	Barge	7	5.894	11.3715	12.943	0.132	30.000
Liquid	20	Rail	389	11.464	28.2030	13.810	0.024	62.500
Liquid	20	Truck	2005	17.530	28.7988	18.584	2.062	68.290

Table B-14. (continued)

Physical state	CMCL	Mode of transportation	Number of data records (N)	Mean	Standard deviation	Upper 90% confidence limit	Median	90th Percentile
Liquid	25	Air	379	11.577	23.1801	13.529	1.120	50.000
Liquid	25	Barge	43	12.323	25.3477	18.662	0.588	56.970
Liquid	25	Rail	1667	8.125	24.2840	9.100	0.020	20.000
Liquid	25	Truck	17581	10.108	22.2259	10.383	1.091	33.333
Liquid	95	Air	94	25.897	33.7606	31.608	10.000	100.000
Liquid	95	Barge	32	10.018	25.4415	17.394	0.851	55.909
Liquid	95	Rail	2516	5.294	19.5042	5.931	0.012	5.609
Liquid	95	Truck	20527	13.264	25.2236	13.552	2.000	50.000
Solid	10	Air	1	3.333	---	---	3.333	3.333
Solid	10	Rail	7	14.480	37.7125	37.856	0.061	100.000
Solid	10	Truck	341	9.796	22.8771	11.828	1.224	25.000
Solid	30	Air	4	14.174	12.7232	24.607	15.625	25.000
Solid	30	Barge	3	1.010	1.7494	2.667	0.000	3.030
Solid	30	Rail	79	9.789	28.5600	15.059	0.007	44.118
Solid	30	Truck	366	5.332	17.2089	6.808	0.180	11.111
Solid	35	Air	9	30.392	35.2536	49.664	16.667	100.000
Solid	35	Barge	3	5.672	9.5221	14.689	0.303	16.667
Solid	35	Rail	208	19.529	33.6799	23.358	1.551	100.000
Solid	35	Truck	1270	10.784	23.3429	11.858	0.946	33.333
Solid	60	Air	33	7.854	20.1050	13.594	0.313	34.000
Solid	60	Barge	15	2.555	6.6186	5.358	0.395	12.812
Solid	60	Rail	177	5.037	17.8456	7.237	0.120	6.317
Solid	60	Truck	2968	8.657	21.1479	9.293	0.625	25.000

Table B-15. Analysis of Variance Results for the Percent of Container Contents Released (CONTREL) by the Commodity Class (DOT Hazard Class)

ANALYSIS OF VARIANCE PROCEDURE
CLASS LEVEL INFORMATION

Class	Levels	Values
Class	3	Gas Liquid Solid

NUMBER OF OBSERVATIONS IN DATA SET = 55,296

DEPENDENT VARIABLE: CONTREL

Source	DF	Sum of squares	Mean square	F-value	PR > F	R-square	C.V.
Model	2	1129880.15028464	59940.37514232	40.02	0.0001	0.001521	128.9319
Error	52554	78713213.46179260	1497.75875217		Root Mse		CONTREL Mean
Corrected Total	52556	78833094.21207720			38.70088826		30.01654425

Source	DF	ANOVA SS	F-value	PR > F
Class	2	119880.75025464	40.02	0.0001

Table B-16. Analysis of Variance Results for the Percent of Container Contents Released (CONTREL) by the Mode of Transportation

```
                              ANALYSIS OF VARIANCE PROCEDURE
                                 CLASS LEVEL INFORMATION
                          Class      Levels      Values
                          Mode         4         Air Barge Rail Truck

                          NUMBER OF OBSERVATIONS IN DATA SET  =  55,296

DEPENDENT VARIABLE:  CONTREL

--------------------------------------------------------------------------------------------------------
Source              DF      Sum of squares       Mean square       F-value      PR > F      R-square         C.V.
--------------------------------------------------------------------------------------------------------

Model                3     2468844.09275027    822948.03091676     566.34       0.0001      0.031317     126.9947

Error            52553    76364250.11932690      1453.09021596                  Root Mse                 CONTREL Mean

Corrected Total  52556    78833094.21207720                                     38.11942046               30.01654425

Source              DF     ANOVA SS            F-value           PR > F

Class                3     2468844.09275027       566.34           0.0001
--------------------------------------------------------------------------------------------------------
```

Table B-17. Summary Statistics for the Percent of Container Contents Released (CONTREL) for Each Physical State (Solid, Liquid, Gas)

Physical state	Number of data records (N)	Mean	Standard deviation	Upper 90% confidence limit	Median	90th Percentile
Gas	1,680	22.0186	38.0087	23.5394	0.04962	100
Liquid	45,482	30.1369	38.6531	30.4341	7.27273	100
Solid	5,395	31.4928	39.3124	32.3705	9.09091	100

Table B-18. Summary Statistics for the Percent of Container Contents Released (CONTREL) by the Mode of Transportation

Physical state	Number of data records (N)	Mean	Standard deviation	Upper 90% confidence limit	Median	90th Percentile
Air	594	16.7608	28.4926	18.6781	1.96154	52.8977
Barge	110	10.8142	24.7357	14.6820	0.54710	33.2885
Rail	6,130	7.0591	22.7003	7.5346	0.01238	10.0000
Truck	46,251	12.0090	24.3063	12.1944	1.49254	40.0000
All		11.26				

Table B-19. Summary Statistics for the Percent of Container Contents Released (CONTREL) by the Physical State and Mode of Transportation

Physical state	Number of data records (N)	Mean	Standard deviation	Upper 90% confidence limit	Median	90th Percentile
Gas	Air	9	81.9729	36.8916	57.3785	106.567
Gas	Barge	6	55.1834	49.8122	14.5119	95.855
Gas	Rail	1043	5.1787	20.7024	3.8966	6.461
Gas	Truck	622	49.0691	43.3285	45.5945	52.544
Liquid	Air	534	27.6085	36.1999	24.4754	30.742
Liquid	Barge	83	28.2776	36.7816	20.2030	36.352
Liquid	Rail	4608	10.7230	27.7564	9.9052	11.541
Liquid	Truck	40257	32.3964	39.1327	32.0064	32.787
Solid	Air	46	30.5908	39.9684	18.8047	42.377
Solid	Barge	21	21.3520	32.1740	7.3101	35.394
Solid	Rail	469	28.9877	40.7142	25.2276	32.748
Solid	Truck	4859	31.7869	39.1929	30.6624	32.911

Table B-20. Analysis of Variance Results for the Percent of Container Contents Released (CONTREL) by Physical State (Liquid) for Commodity (DOT Hazard) Classes 2, 4, 6, 8, 9, 20, 25, and 95

CLASS = LIQUID
ANALYSIS OF VARIANCE PROCEDURE
CLASS LEVEL INFORMATION

Class	Levels	Values
CMCL	8	2 4 6 8 9 20 25 95

NUMBER OF OBSERVATIONS IN DATA SET = 47,892

DEPENDENT VARIABLE: CONTREL

Source	DF	Sum of squares	Mean square	F-value	PR > F	R-square	C.V.
Model	7	1088395.82223689	155485.11746241	105.75	0.0001	0.016017	127.2370
Error	45474	66863005.11495260	1470.35679982		Root Mse		CONTREL Mean
Corrected Total	45481	67951400.93718950			38.34523177		30.13686346
Source	DF	ANOVA SS	F-value	PR > F			
Class	7	1088395.82223689	105.75	0.0001			

Table B-21. Analysis of Variance Results for the Percent of Container Contents Released (CONTREL) by Physical State (Solid) for Commodity (DOT Hazard) Classes 10, 30, 35, and 60

CLASS = SOLID
ANALYSIS OF VARIANCE PROCEDURE
CLASS LEVEL INFORMATION

Class	Levels	Values
CMCL	4	10 30 35 60

NUMBER OF OBSERVATIONS IN DATA SET = 5,429

DEPENDENT VARIABLE: CONTREL

Source	DF	Sum of squares	Mean square	F-value	PR > F	R-square	C.V.
Model	3	117284.84030121	39094.94676707	25.64	0.0001	0.014069	123.9831
Error	5391	8218937.85536569	1524.56647289		Root Mse		CONTREL Mean
Corrected Total	5394	8336222.69566690			39.04569724		31.49276773
Source	DF	ANOVA SS	F-value	PR > F			
Class	3	117284.84030121	25.64	0.0001			

Table B-22. Analysis of Variance Results for the Percent of Container Contents Released (CONTREL) by Physical State (Gas) for Commodity (DOT Hazard) Classes 45, 50, 55, and 65

CLASS = GAS
ANALYSIS OF VARIANCE PROCEDURE
CLASS LEVEL INFORMATION

Class	Levels	Values
CMCL	4	45 50 55 65

NUMBER OF OBSERVATIONS IN DATA SET = 1,975

DEPENDENT VARIABLE: CONTREL

Source	DF	Sum of squares	Mean square	F-value	PR > F	R-square	C.V.
Model	3	24934.82398589	8311.60799530	5.80	0.0006	0.010280	171.8852
Error	1676	2400655.00495708	1432.37172133		Root Mse		CONTREL Mean
Corrected Total	1679	2425589.82894297			37.84668706		22.01857786
Source	DF	ANOVA SS	F-value	PR > F			
Class	3	24934.82398589	5.80	0.0006			

significant differences between the physical states within each commodity (DOT hazard) (P-values < .10).

Summary statistics for the percent of container contents released classified by commodity (DOT hazard) class and physical state are listed in Table B-23.

The fourth sequence of ANOVAs was performed on the percent of container contents released to investigate the significance of mode of transportation within each physical state sorted by commodity class. The P-values of the ANOVA results, which are found in Table B-24, show that for some of the physical state/commodity class combinations (cases with P-value < .10), the mode of transportation was significant. Summary statistics for the percent of container contents released classified by commodity class, physical state, and mode of transportation are displayed in Table B-25. Note, however, that results obtained from the small number of data records (< 10 records) are unreliable.

B.7 Frequency Distribution and Chi-Square Test of Homogeneity Results for the Percent of Shipment Released

The records of percent of shipment released were classified into five groups (intervals) defined as follows:

Group	Percent of shipment released
1	$0 < \text{SHIPREL} \leq 20\%$
2	$20 < \text{SHIPREL} \leq 40\%$
3	$40 < \text{SHIPREL} \leq 60\%$
4	$60 < \text{SHIPREL} \leq 80\%$
5	$80 < \text{SHIPREL} \leq 100\%$

The first Chi-Square test of homogeneity was performed on the percent of shipment released compared to the frequency distributions for the three physical states. The frequency distribution for each physical state and the Chi-Square test results were presented in Table B-4. Also, percentage frequency histograms (percentage bar charts) for physical states are shown in Figures B-1, B-2, and B-3. These figures illustrate that the frequency distributions of the SHIPREL for the three physical states are different. The Chi-Square test results confirmed this observation (P-value < .10).

The second Chi-Square test of homogeneity was performed on the percent of shipment released for each commodity class separately to compare the frequency distributions for the physical states. The results are presented in Tables B-26 (liquids), B-27 (solids), and B-28 (gas);

Table B-23. Summary Statistics for the Percent of Container Contents Released (CONTREL) by the Commodity Class (DOT Hazard Class) and Physical State

Physical state	CMCL	Number of data records (N)	Mean	Standard deviation	Upper 90% confidence limit	Median	90th Percentile
Gas	45	708	25.5146	40.5842	28.0160	0.093	
Gas	50	925	18.7533	35.3042	20.6570	0.019	100.000
Gas	55	21	32.0308	44.4022	47.9214	6.489	100.000
Gas	65	26	34.8997	42.4623	48.5568	9.091	100.000
Liquid	2	332	46.3385	41.7415	50.0956	36.364	100.000
Liquid	4	52	31.5434	38.2472	40.2419	10.330	100.000
Liquid	6	27	43.5444	40.9765	56.4773	27.600	100.000
Liquid	8	29	73.2245	35.8201	84.1332	100.000	100.000
Liquid	9	213	25.8910	36.4302	29.9846	5.000	100.000
Liquid	20	2396	20.8682	32.5887	21.9601	2.000	86.541
Liquid	25	19579	26.0440	35.9281	26.4651	5.455	100.000
Liquid	95	22854	34.3455	40.7964	34.7880	10.000	100.000
Solid	10	336	43.8933	41.0719	47.5680	25.000	100.000
Solid	30	439	20.5134	35.1684	23.2661	1.818	100.000
Solid	35	1457	34.0679	40.3417	35.8011	11.111	100.000
Solid	60	3163	30.5132	38.7279	31.6425	7.273	100.000

Table B-24. Chi-Square Test of Homogeneity of Results for the Percent of Container Contents Released (CONTREL) by Mode of Transportation for Each Combination of Physical State and Commodity Class (DOT Hazard Class)

Physical state	Commodity class (CMCL)	DOT hazard class	P-value
Liquid	2	ORM-A	.329
	4	ORM-B	.454
	6	ORM-C	.094
	8	ORM-D	.020
	9	ORM-E	.768
	20	Combustible Liquid	.000
	25	Flammable Liquid	.000
	95	Corrosive Material	.000
Solid	10	Organic Peroxide	.997
	30	Flammable Solid	.000
	35	Oxidizer	.000
	60	Poison B	.002
Gas	45	Nonflammable Compressed Gas	.000
	50	Flammable Compressed Gas	.000
	55	Poison A	.848
	65	Irritating Material	.998

Table B-25. Summary Statistics for the Percent of Container Released (CONTREL) by the Mode of Transportation for Each Physical State and Each Commodity Class (DOT Hazard Class)

Physical state	Commodity class (code for DOT hazard class)[a]	Mode of transportation	Number of data records (N)	Mean	Standard deviation	Upper 90% confidence limit	Median	90th Percentile
Gas	45	Air	3	100.000	0.0000	100.000	100.000	100.000
Gas	45	Barge	4	57.721	49.4996	98.311	62.728	100.000
Gas	45	Rail	431	5.278	21.0563	6.941	0.009	0.992
Gas	45	Truck	270	56.514	43.5303	60.859	66.667	100.000
Gas	50	Air	6	72.959	43.4170	100.000	100.000	100.000
Gas	50	Barge	1	100.000	--	--	100.000	100.000
Gas	50	Rail	609	5.118	20.5240	6.481	0.003	1.975
Gas	50	Truck	309	44.312	42.1445	48.244	36.364	100.000
Gas	55	Rail	3	3.351	5.7583	8.803	0.050	10.000
Gas	55	Truck	18	36.811	46.3274	54.719	7.444	100.000
Gas	65	Air	0	--	--	--	--	--
Gas	65	Barge	1	0.216	--	--	0.216	0.216
Gas	65	Truck	25	36.287	42.7323	50.503	9.091	100.000
Liquid	2	Air	37	44.125	39.7553	54.843	50.000	100.000
Liquid	2	Rail	18	36.738	44.9297	54.105	10.694	100.000
Liquid	2	Truck	277	47.258	41.8516	51.382	36.364	100.000
Liquid	4	Air	17	59.955	42.3318	76.793	80.000	100.000
Liquid	4	Rail	3	2.402	4.0504	6.237	0.124	7.078
Liquid	4	Truck	32	19.182	28.2501	27.372	5.227	74.750
Liquid	6	Rail	2	49.725	70.2651	100.000	49.725	99.410
Liquid	6	Truck	25	43.050	40.1229	56.210	27.600	100.000
Liquid	8	Air	4	53.733	34.9949	82.429	50.000	100.000
Liquid	8	Truck	25	76.343	35.6427	88.034	100.000	100.000
Liquid	9	Barge	1	2.857	--	--	2.857	2.857
Liquid	9	Rail	21	21.602	34.9612	38.114	7.514	100.000
Liquid	9	Truck	191	26.043	36.7334	30.402	5.000	100.000

Table B-25 (continued)

Physical state	Commodity class (code for DOT hazard class)[a]	Mode of transportation	Number of data records (N)	Mean	Standard deviation	Upper 90% confidence limit	Median	90th Percentile
Liquid	20	Air	6	58.336	38.1618	83.886	55.000	100.000
Liquid	20	Barge	7	5.913	11.3605	12.955	0.152	30.000
Liquid	20	Rail	388	11.785	28.3146	14.143	0.024	64.316
Liquid	20	Truck	1995	22.575	33.0452	23.788	3.333	89.336
Liquid	25	Air	377	19.958	31.1363	22.588	3.500	80.000
Liquid	25	Barge	43	29.903	36.5267	39.038	8.485	100.000
Liquid	25	Rail	1665	12.739	29.7910	13.936	0.020	66.667
Liquid	25	Truck	17494	27.432	36.2851	27.882	7.273	100.000
Liquid	95	Air	93	43.032	41.3037	50.056	25.000	100.000
Liquid	95	Barge	32	31.780	39.9485	43.362	9.545	100.000
Liquid	95	Rail	2511	8.890	25.7385	9.732	0.012	27.273
Liquid	95	Truck	20218	37.471	41.2103	37.946	16.000	100.000
Solid	10	Air	1	10.000	--	--	10.000	10.000
Solid	10	Rail	7	21.667	36.6178	44.365	0.061	100.000
Solid	10	Truck	328	44.471	41.0993	48.193	25.000	100.000
Solid	30	Air	4	54.278	53.2086	97.909	58.333	100.000
Solid	30	Barge	3	4.049	6.9904	10.668	0.026	12.121
Solid	30	Rail	79	14.312	33.5832	20.509	0.008	100.000
Solid	30	Truck	353	21.658	35.2059	24.732	2.273	100.000
Solid	35	Air	9	58.039	45.1660	82.730	75.000	100.000
Solid	35	Barge	3	19.670	32.4649	50.409	1.818	57.143
Solid	35	Rail	207	39.669	44.0629	44.692	15.152	100.000
Solid	35	Truck	1238	32.992	39.5760	34.837	10.000	100.000
Solid	60	Air	32	20.553	33.3119	30.211	1.653	100.000
Solid	60	Barge	15	25.149	35.2286	40.066	6.591	100.000
Solid	60	Rail	176	23.303	36.4973	27.815	1.818	100.000
Solid	60	Truck	2940	31.081	38.8852	32.257	8.864	100.000

[a] Refer to Table 3-3 for the corresponding DOT hazard class.

Source: Statistical analysis of the HAZMAT data base, 1986. (See Appendix B for more details.)

Table B-26. The Frequency Distribution and Chi-Square Test Results for the Percent of Shipment Released (SHIPREL) by Physical State (Liquid)

Class	Group				
Frequency percent (row PCT)	1	2	3	4	Total
2	236 0.52 77.63	26 0.06 8.55	30 0.07 9.87	12 0.03 3.95	304 0.67
4	44 0.10 80.00	5 0.01 9.09	2 0.00 3.64	4 0.01 7.27	55 0.12
6	21 0.05 72.41	2 0.00 6.90	2 0.00 6.90	4 0.01 13.79	29 0.06
8	30 0.07 96.77	0 0.00 0.00	1 0.00 3.23	0 0.00 0.00	31 0.07
9	223 0.49 92.92	13 0.03 5.42	3 0.01 1.25	1 0.00 0.42	240 0.53
20	1919 4.21 83.84	164 0.36 7.16	126 0.28 5.50	80 0.18 3.49	2289 5.02
25	17518 38.44 91.37	870 1.91 4.54	552 1.21 2.88	232 0.51 1.21	19172 42.07
95	21069 46.23 89.83	1390 3.05 5.93	817 1.79 3.48	179 0.39 0.76	23455 51.46
Total	41060 90.09	2470 5.42	1533 3.36	512 1.12	45575 100.00

Frequency Missing = 2,317.

Table B-26. (continued)

Statistics for Table of Class by Group

Statistic	Degrees of freedom (DF)	Value	Probability (P-value)
Chi-Square	21	394.998	0.000
Likelihood Ratio Chi-Square	21	294.348	0.000
Mantel-Haenszel Chi-Square	1	5.212	0.022
PHI		0.093	
Contingency Coefficient		0.093	
Cramer's V		0.054	

Effective Sample Size = 45,575.

Table B-27. The Frequency Distribution and Chi-Square Test of Homogeneity Results for the Percent of Shipment Released (SHIPREL) by Physical State (Solid)

Class	Group				
Frequency percent (row PCT)	1	2	3	4	Total
10	299	14	6	3	322
	5.76	0.27	0.12	0.06	6.20
	92.86	4.35	1.86	0.93	
30	414	10	5	1	430
	7.97	0.19	0.10	0.02	8.28
	96.28	2.33	1.16	0.23	
35	1248	82	47	8	1385
	24.02	1.58	0.90	0.15	26.66
	90.11	5.92	3.39	0.58	
60	2850	117	73	18	3058
	54.86	2.25	1.41	0.35	58.86
	93.20	3.83	2.39	0.59	
Total	4811	223	131	39	5195
	92.61	4.29	2.52	0.58	100.00

Frequency Missing = 234.

Statistics for Table of Class by Group

Statistic	Degrees of freedom (DF)	Value	Probability (P-value)
Chi-Square	9	25.346	0.003
Likelihood Ratio Chi-Square	9	25.869	0.002
Mantel-Haenszel Chi-Square	1	0.674	0.412
PHI		0.070	
Contingency Coefficient		0.070	
Cramer's V		0.040	

Effective Sample Size = 5,195.

Table B-28. The Frequency Distribution and Chi-Square Test of Homogeneity Results for the Percent of Shipment Released (SHIPREL) by Physical State (Gas)

Class	Group				
Frequency percent row PCT	1	2	3	4	Total
45	722 39.56 92.92	24 1.32 3.09	20 1.10 2.57	11 0.60 1.42	777 42.58
50	935 51.23 94.16	21 1.15 2.11	23 1.26 2.32	14 0.77 1.41	993 54.41
55	21 1.15 91.30	1 0.05 4.35	1 0.05 4.35	0 00.00 0.00	23 1.26
65	29 1.59 90.63	1 0.05 3.13	1 0.05 3.13	1 0.05 3.13	32 1.75
Total	1707 93.53	47 2.58	45 2.47	26 1.42	1825 100.00

Frequency Missing = 150.

Statistics for Table of Class by Group

Statistic	Degrees of freedom (DF)	Value	Probability (P-value)
Chi-Square	9	3.538	0.939
Likelihood Ratio Chi-Square	9	3.589	0.936
Mantel-Haenszel Chi-Square	1	0.011	0.915
PHI		0.044	
Contingency Coefficient		0.044	
Cramer's V		0.0250	

Effective Sample Size = 1,825.

they show that the frequency distributions for the physical state within each commodity (DOT hazard) class are significantly different.

The third Chi-Square test was performed on the percent of shipment released to compare the frequency distributions for modes of transportation. The results, provided in Table B-29, show that the frequency distributions for modes of transportation are significantly different. The frequency histograms for each mode are presented in Figures B-4, B-5, B-6, and B-7. Table B-30 lists the resulting P-values (observed significance level) from this test.

The fourth Chi-Square test was performed on the percent of shipment released for each commodity class separately to compare the frequency distributions of modes of transportation. The results are presented in Tables B-31, B-32, and B-33 and show that the frequency distributions of the modes of transportation for liquid chemicals and gas chemicals are significantly different. The results also indicate that the frequency distributions of the modes of transportation carrying solid chemicals are _not_ significantly different (P-value > 0.1). This result implies that the values of percent of shipment released (SHIPREL) for each mode of transportation used to carry solid chemicals are similarly distributed.

The fifth Chi-Square test was performed on the percent of shipment released for each physical state within each DOT hazard class to compare distributions for modes of transportation. The P-values of the Chi-Square tests are listed in Table B-34 and show that the frequency distributions for modes of transportation are significantly different for some of the physical states (cases with P-value < .1).

B.8 Frequency Distribution and Chi-Square Test of Homogeneity Results for the Percent of Container Contents Released

The values for percent fractions of container contents released (CONTROL) were classified into five groups (intervals) defined as follows:

Group	Percent of shipment released
1	$0 < \text{CONTREL} \leq 20\%$
2	$20 < \text{CONTREL} \leq 40\%$
3	$40 < \text{CONTREL} \leq 60\%$
4	$60 < \text{CONTREL} \leq 80\%$
5	$80 < \text{CONTREL} \leq 100\%$

The first Chi-Square test of homogeneity was performed on the percent of container contents released to compare the frequency distributions of the commodity classes. The frequency distributions of the commodity

Table B-29. The Frequency Distribution and Chi-Square Test of Homogeneity Results for the Percent of Shipment Released (SHIPREL) by Mode of Transportation

Class	Group				
Frequency percent (row PCT)	1	2	3	4	Total
Air	499	50	39	11	599
	0.95	0.10	0.07	0.02	1.14
	83.31	8.35	6.51	1.84	
Barge	105	7	1	3	116
	0.20	0.01	0.00	0.01	0.22
	90.52	6.03	0.86	2.59	
Rail	6115	89	68	42	6314
	11.63	0.17	0.13	0.08	12.00
	96.85	1.41	1.08	0.67	
Truck	40859	2594	1601	512	45566
	77.69	4.93	3.04	0.97	86.64
	89.67	5.69	3.51	1.12	
Total	47578	2740	1709	568	52595
	90.46	5.21	3.25	1.08	100.00

Frequency Missing = 2,701.

Statistics for Table of Class by Group

Statistic	Degrees of freedom (DF)	Value	Probability (P-value)
Chi-Square	9	381.539	0.000
Likelihood Ratio Chi-Square	9	479.704	0.000
Mantel-Haenszel Chi-Square	1	51.041	0.001
PHI		0.085	
Contingency Coefficient		0.085	
Cramer's V		0.049	

Effective Sample Size = 52,595.

Table B-30. Chi-Square Test of Homogeneity Results for the Percent of Shipment Released (SHIPREL) by Mode of Transportation for Each Physical State and Each Commodity Class (DOT Hazard Class)

Physical state	Commodity class (CMCL)	DOT hazard class	P-value
Liquid	2	ORM-A	.170
	4	ORM-B	.033
	6	ORM-C	.252
	8	ORM-D	.074
	9	ORM-E	.936
	20	Combustible Liquid	.000
	25	Flammable Liquid	.000
	95	Corrosive Material	.000
Solid	10	Organic Peroxide	.825
	30	Flammable Solid	.575
	35	Oxidizer	.042
	60	Poison B	.200
Gas	45	Nonflammable Compressed Gas	.000
	50	Flammable Compressed Gas	.000
	55	Poison A	.554
	65	Irritating Material	.913

Table B-31. The Frequency Distribution and Chi-Square Test of Homogeneity Results for the Percent of Shipment Released (SHIPREL) by Mode of Transportation for Liquids

Mode Frequency percent (row PCT)	Group 1	 2	 3	 4	 Total
Air	449 0.99 82.99	46 0.10 8.55	35 0.08 6.47	11 0.02 2.03	541 1.19
Barge	80 0.18 89.89	5 0.01 5.62	1 0.00 1.12	3 0.01 3.37	89 0.20
Rail	4598 10.09 96.64	69 0.15 1.45	55 0.12 1.16	36 0.08 0.76	4758 10.44
Truck	35933 78.84 89.41	2350 5.16 5.85	1442 3.16 3.59	462 1.01 1.15	40187 88.18
Total	41060 90.09	2470 5.42	1533 3.36	512 1.12	45575 100.00

Frequency Missing = 2,371.

Statistics for Table of Mode by Group

Statistic	Degrees of freedom (DF)	Value	Probability (P-value)
Chi-Square	9	294.850	0.000
Likelihood Ratio Chi-Square	9	369.332	0.000
Mantel-Haenszel Chi-Square	1	26.387	0.001
PHI		0.080	
Contingency Coefficient		0.080	
Cramer's V		0.046	

Effective Sample Size = 45,575.

Table B-32. The Frequency Distribution and Chi-Square Test of Homogeneity Results for the Percent of Shipment Released (SHIPREL) by Mode of Transportation for Solids

Mode	Group				
Frequency percent (row PCT)	1	2	3	4	Total
Air	38	3	4	0	45
	0.73	0.06	0.08	0.00	0.87
	84.44	6.67	8.89	0.00	
Barge	20	1	0	0	21
	0.38	0.02	0.00	0.00	0.40
	95.24	4.76	0.00	0.00	
Rail	405	12	9	5	431
	7.80	0.23	0.17	0.10	8.30
	93.97	2.78	2.09	1.16	
Truck	4348	207	118	25	4698
	83.70	3.98	2.27	0.48	90.43
	92.55	4.41	2.51	0.53	
Total	4811	223	131	30	5195
	92.61	4.29	2.52	0.58	100.00

Frequency Missing = 234.

Statistics for Table of Mode by Group

Statistic	DF	Value	Prob
Chi-Square	9	14.624	0.102
Likelihood Ratio Chi-Square	9	12.342	0.195
Mantel-Haenszel Chi-Square	1	1.036	0.309
PHI		0.053	
Contingency Coefficient		0.053	
Cramer's V		0.031	

Effective Sample Size = 5,195.

Table B-33. The Frequency Distribution and Chi-Square Test of Homogeneity Results for the Percent of Shipment Released (SHIPREL) by Mode of Transportation for Gases

Mode	Group				
Frequency percent (row PCT)	1	2	3	4	Total
Air	12	1	0	0	13
	0.66	0.05	0.00	0.00	0.71
	92.31	7.69	0.00	0.00	
Barge	5	1	0	0	6
	0.27	0.05	0.00	0.00	0.33
	83.33	16.67	0.00	0.00	
Rail	1112	8	4	1	1125
	60.93	0.44	0.22	0.05	61.64
	98.84	0.71	0.36	0.09	
Truck	578	37	41	25	681
	31.67	2.03	2.25	1.37	37.32
	84.88	5.43	6.02	3.67	
Total	1707	47	45	26	1825
	93.53	2.58	2.47	1.42	100.00

Frequency Missing = 150.

Statistics for Table of Mode by Group

Statistic	DF	Value	Prob
Chi-Square	9	145.814	0.000
Likelihood Ratio Chi-Square	9	149.100	0.000
Mantel-Haenszel Chi-Square	1	108.084	0.000
PHI		0.283	
Contingency Coefficient		0.272	
Cramer's V		0.163	

Effective Sample Size = 1,825.

Table B-34. Analysis of Variance Results for the Percent of Shipment Released (SHIPREL) by the Mode of Transportation for Each Physical State and Each Commodity Class

Physical state	Commodity class (CMCL)	DOT hazard class	P-value
Liquid	2	ORM-A	.5527
	4	ORM-B	.0003
	6	ORM-C	.8295
	8	ORM-D	.2482
	9	ORM-E	.8183
	20	Combustible Liquid	.0001
	25	Flammable Liquid	.0001
	95	Corrosive Material	.0001
Solid	10	Organic Peroxide	.2477
	30	Flammable Solid	.0660
	35	Oxidizer	.0377
	60	Poison B	.0275
Gas	45	Nonflammable Compressed Gas	.0001
	50	Flammable Compressed Gas	0001
	55	Poison A	.2362
	65	Irritating Material	.4160

classes and the Chi-Square test results are listed in Table B-35 and show that the frequency distributions for each of the physical states are significantly different. The percentage frequency histograms (percentage bar charts) for the physical states are presented in Figures B-8 (liquids), B-9 (solids), and B-10 (gases).

The second Chi-Square test was performed on the percent of container contents released for each commodity class separately to compare the frequency distributions for the physical states. The results are provided in Tables B-36, B-37, and B-38 and show that the frequency distributions for the physical state within each class are significantly different.

The third Chi-Square test was performed on the percent of container contents released to compare the frequency distributions for modes of transportation. The results, presented in Table B-39, show that the frequency distributions for modes of transportation are significantly different. The percentage histograms for each mode are listed in Figures B-11, B-12, B-13, and B-14.

The fourth Chi-Square test was performed on the percent of container contents released for each commodity class separately to compare the frequency distributions of modes of transportation. The results, which are listed in Tables B-40, B-41, and B-42, show that the frequency distributions for modes of transportation are different for liquid and gas chemicals (P-values <.1), but are not significantly different for solid chemicals (P>.1).

The fifth Chi-Square test was performed on the percent of container contents released for each physical state separately to compare the frequency distributions for modes of transportation. The P-values of the tests show that for some of the physical states, the frequency distributions for modes of transportation are significantly different (cases with P-value <0.1).

B.9 Correlation Between Quantity Released and Shipment Size

Correlation measures the closeness of a linear relationship between two variables. If one variable can be expressed as a linear function of another variable, then the correlation is 1 or -1, depending on whether the two variables are directly or inversely related. A correlation of 0 between two variables means that each variable has no linear predictive ability for the other. The correlation between two variables can be estimated using the sample correlation coefficient. The sample correlations presented in this analysis are known as "Pearson's Correlation Coefficient."

Table B-35. The Frequency Distribution and Chi-Square Test of Homogeneity Results for the Percent of Container Contents Released (CONTREL) by Physical State

Table of Class by Group 2

Class	Group 2					
Frequency percent (row PCT)	1	2	3	4	5	Total
Gas	1542 2.79 78.08	51 0.09 2.58	55 0.10 2.78	32 0.06 1.62	295 0.53 14.94	1975 3.57
Liquid	31107 56.26 64.95	3431 6.20 7.16	2864 5.18 5.98	1288 2.33 2.69	9202 16.64 19.21	47892 86.61
Solid	3364 6.08 61.96	427 0.77 7.87	352 0.64 6.48	124 0.22 2.28	1162 2.10 21.40	5429 9.82
Total	36013 65.13	3909 7.07	3271 5.92	1444 2.61	10659 19.28	55296 100.00

Statistics for Table of Class by Group 2

Statistic	Degrees of freedom (DF)	Value	Probability (P-value)
Chi-Square	8	200.069	0.000
Likelihood Ratio Chi-Square	8	225.655	0.000
Mantel-Haenszel Chi-Square	1	69.386	0.000
PHI		0.060	
Contingency Coefficient		0.060	
Cramer's V		0.043	

Sample size = 55,296.

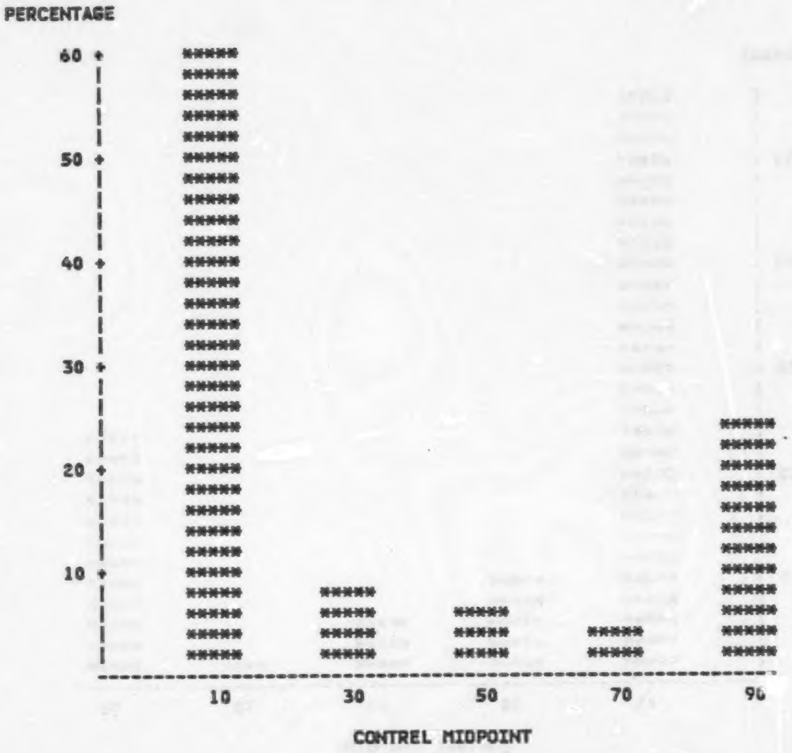

Figure B-8. Percentage bar chart for the frequency distribution of the percent of container released for liquids.

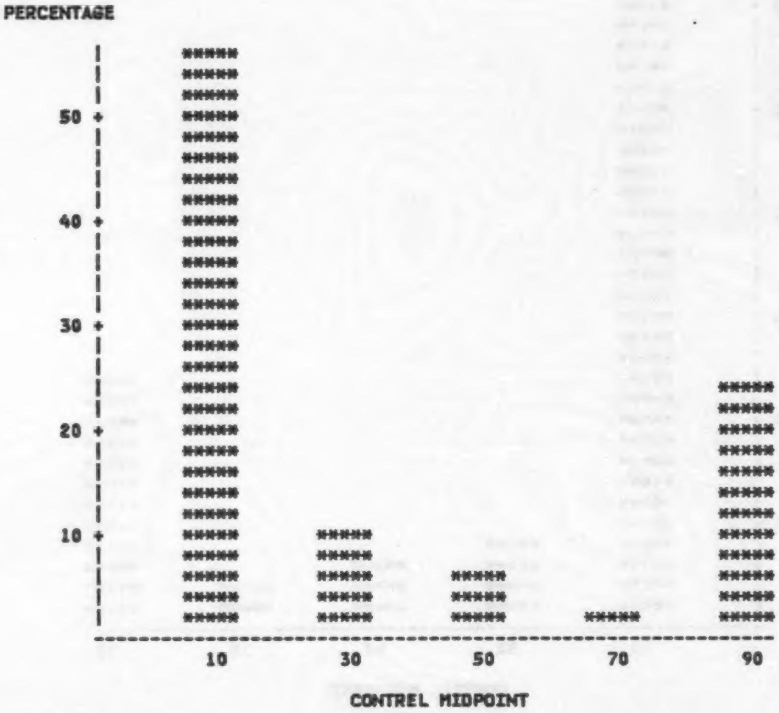

Figure B-9. Percentage bar chart for the frequency distribution of the percent of container released for solids.

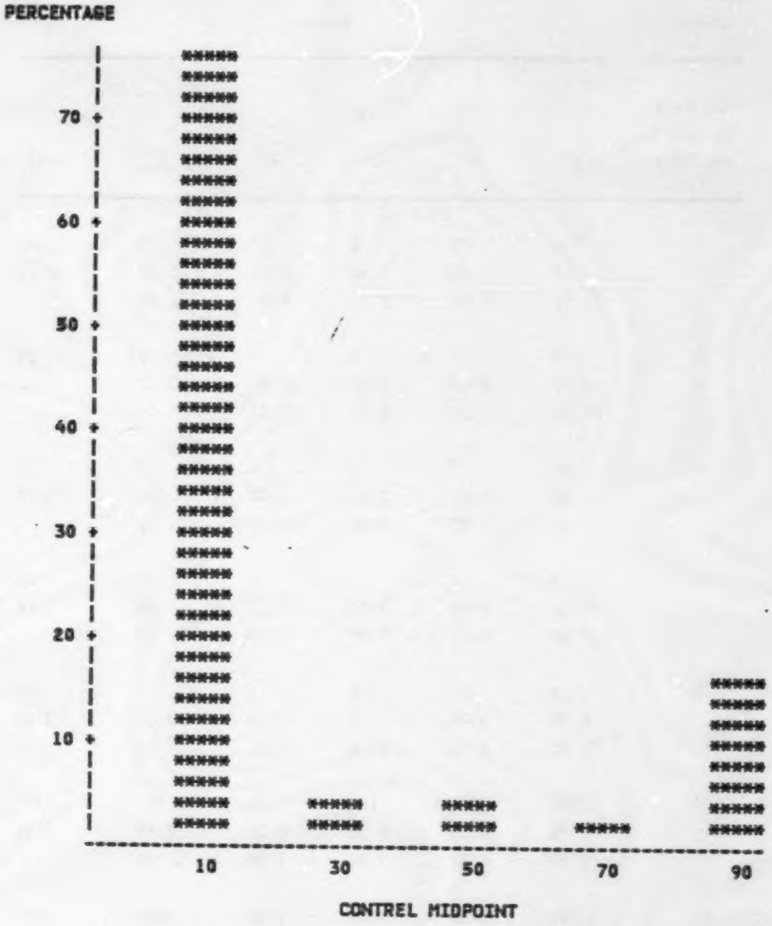

Figure B-10. Percentage bar chart for the frequency distribution of the percent of container released for gases.

Table B-36. The Frequency Distribution and Chi-Square Test of Homogeneity Results for the Percent of Container Contents Released (CONTREL) by Physical State (Liquid)

Physical State = Liquid
Table of Commodity Class by Group 2

Commodity class	Group 2					
Frequency percent (row PCT)	1	2	3	4	5	Total
2	156	29	30	17	110	342
	0.33	0.06	0.06	0.04	0.23	0.71
	45.61	8.48	8.77	4.97	32.16	
4	39	7	0	5	9	60
	0.08	0.01	0.00	0.01	0.02	0.13
	65.00	11.67	0.00	8.33	15.00	
6	18	3	1	4	7	33
	0.04	0.01	0.00	0.01	0.01	0.07
	54.55	9.09	3.03	12.12	21.21	
8	7	1	3	2	18	31
	0.01	0.00	0.01	0.00	0.04	0.06
	22.58	3.23	9.68	6.45	58.06	
9	179	21	8	2	37	247
	0.37	0.04	0.02	0.00	0.08	0.52
	72.47	8.50	3.24	0.81	14.98	
20	1793	171	144	98	367	2473
	3.74	0.36	0.30	0.20	0.56	5.16
	72.50	6.91	5.82	3.96	10.80	
25	13645	1453	1206	592	3097	19993
	28.49	3.03	2.52	1.24	6.47	41.75
	68.25	7.27	6.03	2.96	15.49	
95	15270	1746	1472	568	5657	24713
	31.88	3.65	3.07	1.19	11.81	51.60
	61.79	7.07	5.96	2.30	22.89	
Total	31107	3431	2864	1288	9202	47892
	64.95	7.16	5.98	2.69	19.21	100.00

Table B-36. (continued)

Statistics for Table of Class by Group 2

Statistic	Degrees of freedom (DF)	Value	Probability (P-value)
Chi-Square	28	672.003	0.000
Likelihood Ratio Chi-Square	28	674.392	0.000
Mantel-Haenszel Chi-Square	1	342.281	0.000
PHI		0.118	
Contingency Coefficient		0.118	
Cramer's V		0.059	

Sample size = 47,892.

Table B-37. The Frequency Distribution and Chi-Square Test of Homogeneity Results for the Percent of Container Contents Released (CONTREL) by Physical State (Solid)

Physical State = Solid
Table of Commodity Class by Group 2

Commodity class Frequency percent (row PCT)	Group 2 1	2	3	4	5	Total
10	149	44	33	6	105	337
	2.74	0.81	0.61	0.11	1.93	6.21
	44.21	13.06	9.79	1.78	31.16	
30	343	18	10	9	64	444
	6.32	0.33	0.18	0.17	1.18	8.18
	77.25	4.05	2.25	2.03	14.41	
35	873	122	94	30	355	1474
	16.08	2.25	1.73	0.55	6.54	27.15
	59.23	8.28	6.38	2.04	24.08	
60	1999	243	215	79	638	3174
	36.82	4.48	3.96	1.46	11.75	58.46
	62.98	7.66	6.77	2.49	20.10	
Total	3364	427	352	124	1162	5429
	61.96	7.87	6.48	2.28	21.40	100.00

Statistics for Table of Class by Group 2

Statistic	Degrees of freedom (DF)	Value	Probability (P-value)
Chi-Square	12	108.888	0.000
Likelihood Ratio Chi-Square	12	112.189	0.000
Mantel-Haenszel Chi-Square	1	12.133	0.000
PHI		0.142	
Contingency Coefficient		0.140	
Cramer's V		0.082	

Sample size = 5,429.

Table B-38. The Frequency Distribution and Chi-Square Test of Homogeneity Results for the Percent of Container Contents Released (CONTREL) by Physical State (Gas)

Physical State = Gas
Table of Commodity Class by Group 2

Commodity class	Group 2					
Frequency percent (row PCT)	1	2	3	4	5	Total
45	644	24	20	13	151	852
	32.61	1.22	1.01	0.66	7.65	43.14
	75.59	2.82	2.35	1.53	17.72	
50	854	23	34	19	131	1061
	43.24	1.16	1.72	0.96	6.63	53.72
	80.49	2.17	3.20	1.79	12.35	
55	20	1	0	0	6	27
	1.01	0.05	0.00	0.00	0.30	1.37
	74.07	3.70	0.00	0.00	22.22	
65	24	3	1	0	7	35
	1.22	0.15	0.05	0.00	0.35	1.77
	68.57	8.57	2.86	0.00	20.00	
Total	1542	51	55	32	295	1975
	78.08	2.58	2.78	1.62	14.94	100.00

Statistics for Table of Class by Group 2

Statistic	Degrees of freedom (DF)	Value	Probability (P-value)
Chi-Square	12	21.813	0.040
Likelihood Ratio Chi-Square	12	21.614	0.042
Mantel-Haenszel Chi-Square	1	1.750	0.186
PHI		0.105	
Contingency Coefficient		0.105	
Cramer's V		0.061	

Sample size = 1,975.

Table B-39. The Frequency Distribution and Chi-Square Test of Homogeneity Results for the Percent of Container Contents Released (CONTREL) by Mode of Transportation

Table of Mode by Group 2

Mode	Group 2					
Frequency percent (row PCT)	1	2	3	4	5	Total
Air	425	43	56	16	102	642
	0.77	0.08	0.10	0.03	0.18	1.16
	66.20	6.70	8.72	2.49	15.89	
Barge	78	14	6	5	19	122
	0.14	0.03	0.01	0.01	0.03	0.22
	63.93	11.48	4.92	4.10	15.57	
Rail	5793	146	107	62	511	6619
	10.48	0.26	0.19	0.11	0.93	11.97
	87.52	2.21	1.62	0.94	7.72	
Truck	29717	3706	3102	1361	10027	47913
	53.74	6.70	5.61	2.46	18.13	86.65
	62.02	7.73	6.47	2.84	20.93	
Total	36013	3909	3271	1444	10659	55296
	65.13	7.07	5.92	2.61	19.28	100.00

Statistics for Table of Mode by Group 2

Statistic	Degrees of freedom (DF)	Value	Probability (P-value)
Chi-Square	12	1689.304	0.000
Likelihood Ratio Chi-Square	12	1961.651	0.000
Mantel-Haenszel Chi-Square	1	682.348	0.000
PHI		0.175	
Contingency Coefficient		0.172	
Cramer's V		0.101	

Sample size = 55,296.

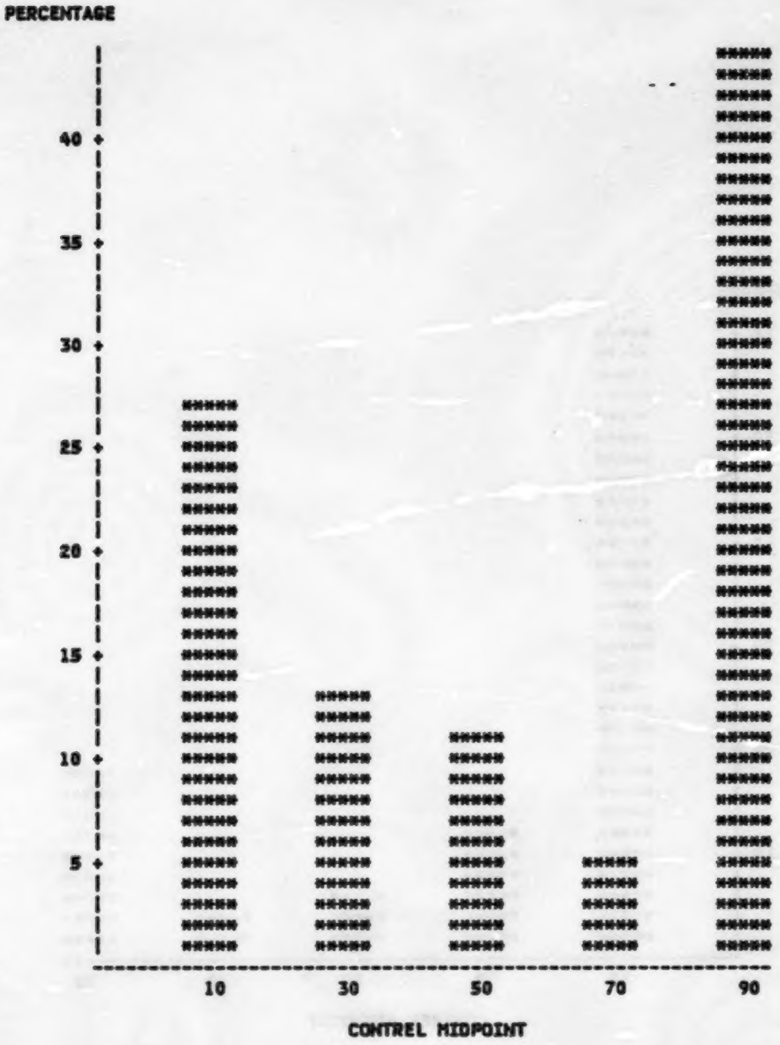

Figure B-11. Percentage bar chart for the frequency distribution of the percent of container released for the air mode of transportation.

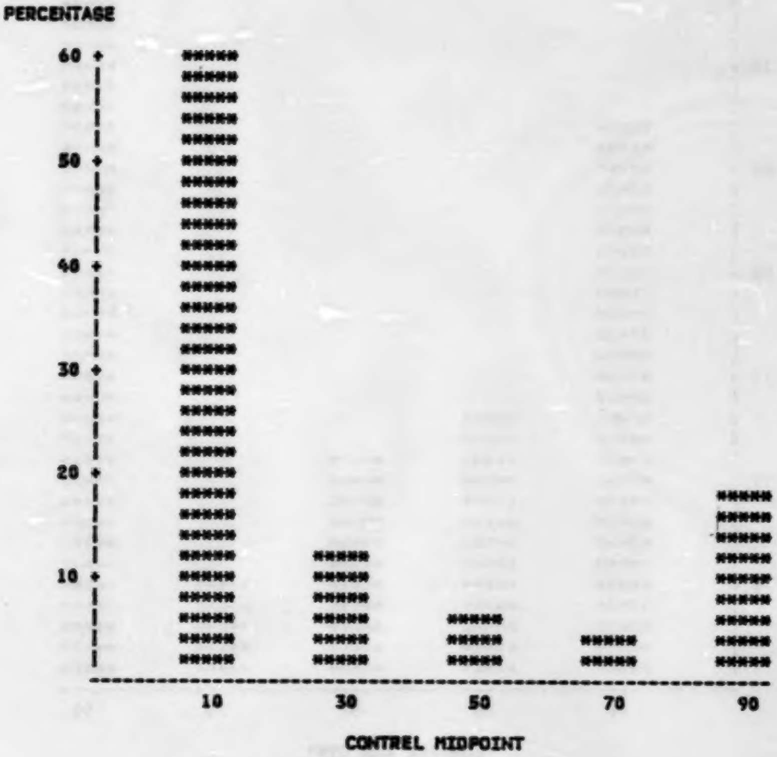

Figure B-12. Percentage bar chart for the frequency distribution of the percent of container released for the water mode of transportation.

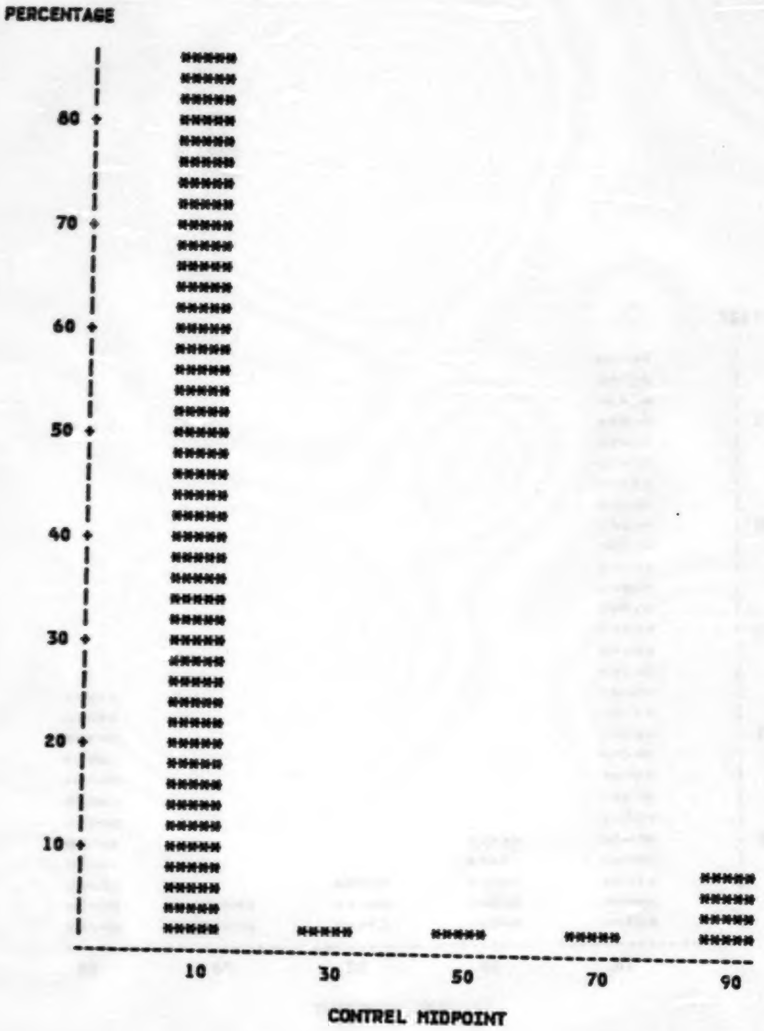

Figure B-13. Percentage bar chart for the frequency distribution of the percent of container released for the rail mode of transportation.

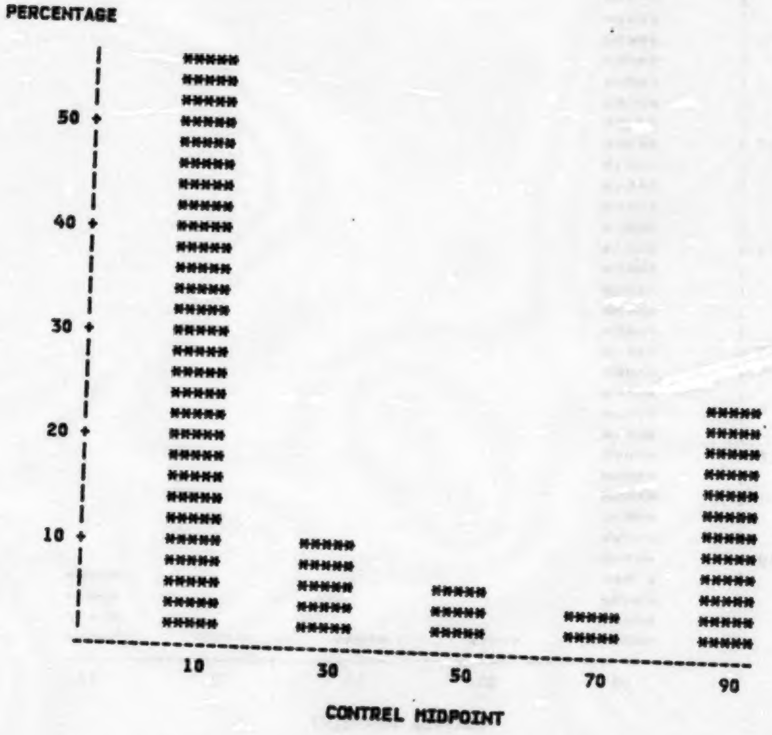

Figure B-14. Percentage bar chart for the frequency distribution of the percent of container released for the highway mode of transportation.

Table B-40. The Frequency Distribution and Chi-Square Test of Homogeneity Results for the Percent of Container Contents Released (CONTREL) by Mode of Transportation for Liquids

Physical State = Liquid
Table of Mode by Group 2

Mode	Group 2					
Frequency percent (row PCT)	1	2	3	4	5	Total
Air	384	39	54	15	85	577
	0.80	0.08	0.11	0.03	0.18	1.20
	66.55	6.76	9.36	2.60	14.73	
Barge	60	10	5	4	14	93
	0.13	0.02	0.01	0.01	0.03	0.19
	64.52	10.75	5.38	4.30	15.05	
Rail	4370	111	87	51	358	4977
	9.12	0.23	0.18	0.11	0.75	10.39
	87.80	2.23	1.75	1.02	7.19	
Truck	26293	3271	2718	1218	8745	42245
	54.90	6.83	5.68	2.54	18.26	88.21
	62.24	7.74	6.43	2.88	20.70	
Total	31107	3431	2864	1288	9202	47892
	64.96	7.16	5.98	2.69	19.21	100.00

Statistics for Table of Mode by Group 2

Statistic	Degrees of freedom (DF)	Value	Probability (P-value)
Chi-Square	12	1301.456	0.000
Likelihood Ratio Chi-Square	12	1514.345	0.000
Mantel-Haenszel Chi-Square	1	513.124	0.000
PHI		0.165	
Contingency Coefficient		0.163	
Cramer's V		0.095	

Sample size = 47,892.

Table B-41. The Frequency Distribution and Chi-Square Test of Homogeneity Results for the Percent of Container Contents Released (CONTREL) by Mode of Transportation for Solids

Physical State = Solids
Table of Mode by Group 2

Mode	Group 2					
Frequency percent (row PCT)	1	2	3	4	5	Total
Air	31 0.57 65.96	3 0.06 6.38	2 0.04 4.26	1 0.02 2.13	10 0.18 21.28	47 0.87
Barge	14 0.26 66.67	3 0.06 14.29	1 0.02 4.76	1 0.02 4.76	2 0.04 9.52	21 0.39
Rail	312 5.75 66.24	27 0.50 5.73	16 0.29 3.40	10 0.18 2.12	106 1.95 22.51	471 8.68
Truck	3007 55.39 61.49	394 7.26 8.06	333 6.13 6.81	112 2.06 2.29	1044 19.23 21.35	4890 90.07
Total	3364 61.96	427 .87	352 6.48	124 2.28	1162 21.40	5429 100.00

Statistics for Table of Mode by Group 2

Statistic	Degrees of freedom (DF)	Value	Probability (P-value)
Chi-Square	12	16.409	0.173
Likelihood Ratio Chi-Square	12	18.196	0.110
Mantel-Haenszel Chi-Square	1	0.875	0.349
PHI		0.055	
Contingency Coefficient		0.055	
Cramer's V		0.032	

Sample size = 5,429.

Table B-42. The Frequency Distribution and Chi-Square Test of Homogeneity Results for the Percent of Container Contents Released (CONTREL) by Mode of Transportation for Gases

Physical State = Gas
Table of Mode by Group 2

Mode	Group 2					
Frequency percent (row PCT)	1	2	3	4	5	Total
Air	10	1	0	0	7	18
	0.51	0.05	0.00	0.00	0.35	0.91
	55.56	5.56	0.00	0.00	38.89	
Barge	4	1	0	0	3	8
	0.20	0.05	0.00	0.00	0.15	0.41
	50.00	12.50	0.00	0.00	37.50	
Rail	1111	8	4	1	47	1171
	56.25	0.41	0.20	0.05	2.38	59.29
	94.88	0.68	0.34	0.09	4.01	
Truck	417	41	51	31	238	778
	21.11	2.08	2.58	1.57	12.05	39.39
	53.60	5.27	6.56	3.98	30.59	
Total	1542	51	55	32	295	1975
	78.08	2.58	2.78	1.62	14.94	100.00

Statistics for Table of Mode by Group 2

Statistic	Degrees of freedom (DF)	Value	Probability (P-value)
Chi-Square	12	486.446	0.000
Likelihood Ratio Chi-Square	12	507.943	0.000
Mantel-Haenszel Chi-Square	1	270.767	0.000
PHI		0.496	
Contingency Coefficient		0.445	
Cramer's V		0.287	

Sample size = 1,975.

The correlation discussed in this study is between the quantity released and the shipment size. The correlation coefficients for the data, classified by physical states and commodity classes, are presented in Table B-43.

The correlation coefficients presented in Table B-43 showed a positive correlation between the shipment size and the quantity released. These coefficients are relatively high for commodity classes 2, 6, and 50. A statistical test of the significance of the correlation coefficients in Table B-43 was not performed because the assumption that the data were normally distributed was not valid.

B.10 Conclusion

The results presented in this report indicate that the percent of shipment released (SHIPREL) has different statistical characteristics for each of the three physical states (liquid, solid, and gas), for each mode of transportation, and for each commodity (DOT hazard) class. The analysis of variance test results show that the means of the percent of shipment released (SHIPREL) for the different physical states are significantly different for each factor considered (e.g., DOT hazard class). The Chi-Square test of homogeneity results shows that the frequency distributions of percent of shipment released (SHIPREL) for the various levels of each factor are significantly different.

The analysis of variance method and the Chi-Square technique were also performed on the fraction of container released and show that the means of the percent of container contents released (CONTREL) for the different levels of each factor are significantly different. The analyses also showed that the frequency distributions of the percent of container released (CONTREL) for the various levels of each factor differ significantly as well.

Other factors that were not considered in this study but which could be investigated in the future are the type of container used, the distance traveled, and the location of the incident. The interaction of some of the factors and regression analysis of the quantity of chemical released on the distance traveled should reveal relationships among the various factors.

Table B-43. Correlation Coefficient Between Quantity Released and Shipment Size Classified by Physical States and Commodity Class

Physical state	Commodity class (CMCL)	Correlation coefficient
Liquid	2	.782
	4	.244
	6	.999
	8	.231
	9	.206
	20	.196
	25	.163
	95	.186
Solid	10	.031
	30	.186
	35	.049
	60	.259
Gas	45	.082
	50	.543
	55	.150
	65	.019

APPENDIX C

Methods for Estimating Average Shipping Distances

This appendix presents three alternative methods for estimating average distances over which chemicals are shipped during distribution in commerce. These methods rely on data on shipping patterns in the 1977 Bureau of the Census Commodity Transportation Survey (CTS) publications, including the following:

- Commodity Transportation Survey Summary (USDOC 1981a);
- Commodity Transportation Survey, Geographic Area Series (USDOC 1981b); and
- Commodity Transportation Survey, Commodity Series (USDOC 1981c).

Information on the locations of chemical manufacturers is also useful. One source of such information is the Stanford Research Institute Directory of Chemical Producers, published annually (see SRI 1987).

The appendix is divided into three sections. Section C.1 describes the steps common to all methods, as well as general information on use of the CTS publications. Section C.2 presents criteria for selection of a method. Section C.3 describes each method in detail.

C.1 Steps Common to All Methods

Although each method differs in the type of source information used, four steps are common to all methods. The general steps are as follows:

- Identify the CTS commodity code most closely related to the specific chemical for which shipping data are required.
- Identify the geographic origin of shipments.
- Locate values for tons and ton-miles shipped for the selected commodity code (STCC) and geographic specificity in the CTS publications.
- Calculate the average shipping distances of the chemical for each mode of transportation.

Each of these steps and the sources of information used to complete them are described below.

C.1.1 Identify the CTS Commodity Code

Commodities included in the CTS publications are classified using the Commodity Classification for Transportation Statistics (TCC) codes. The system of numbering within the TCC codes closely parallels that of the

Standard Transportation Commodity Code (STCC 1972, USDOC 1981a). Therefore, for the purposes of this method, the data on commodity shipments in the CTS will be searched by first matching the STCC code obtained in Step 1 of the general method (Section 3.1 of this report) with the most closely related TCC code listed in tables of the CTS publications; the more digits in the TCC code, the more specific the commodity classification.

For example, the STCC code for malathion is 2879978 (STCC 1972). The available TCC commodity codes to match this STCC in the CTS publications are:

28	Chemicals and Allied Products
287	Agricultural Chemicals
28799	Agricultural Chemicals, NEC (USDOC 1981a).

The best match would be TCC 28799. However, as will be explained in the following discussion, sufficient data on commodity shipments are not always available at the greatest level of specificity.

C.1.2 Identify the Geographic Origin of Shipment

For some chemicals, it will be possible to identify the location(s) of manufacture. This information can be used to obtain data from the CTS publications that closely correspond to the actual shipping patterns.

Areas of origin and destination of commodities vary with respect to geographic level of detail depending upon the CTS report used. Data in the CTS Summary (USDOC 1981a) and the CTS Commodity Series (USDOC 1981c) are summarized for the entire United States. In the CTS Geographic Area Series (1981b), data are presented by state of origin and by production area of origin.

Geographic levels of detail included in the CTS, in order from least to most detailed, are census division, state, and production area. Census divisions of the United States include New England, Middle Atlantic, East North Central, West North Central, South Atlantic, East South Central, West South Central, Mountain, and Pacific. Production areas consist of large Standard Metropolitan Statistical Areas (SMSAs) or clusters of SMSAs that represent a single geographic industrial unit having 900 or more manufacturing establishments. Forty-nine SMSAs are defined in the 1977 CTS publications (USDOC 1981a). Table C-1 presents production areas by census division, with descriptions of SMSAs included in each production area.

An up-to-date source of information on plant locations of manufacturers of specific chemicals is the SRI Directory of Chemical Producers (see SRI 1987).

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Table C-1. 1977 Commodity Transportation Survey Production Area Descriptions by Division

(Standard metropolitan statistical areas included in each production area)

NEW ENGLAND

PA 1-1	(Previously PA 1) Boston, Worcester, Providence-Warwick-Pawtucket, Brockton, Lawrence-Haverhill, Lowell
PA 1-2	(Previously PA 2) Hartford, New Britain, Meriden, Waterbury, New Haven-West Haven, Bridgeport, Springfield-Chicopee-Holyoke

MIDDLE ATLANTIC

PA 2-1	(Previously PA 3) New York, Nassau-Suffolk, Norwalk, Stamford
PA 2-2	(Previously PA 4) Newark, Jersey City, Patterson-Clifton-Passaic, New Brunswick-Perth Amboy-Sayreville, Long Branch-Asbury Park
PA 2-3	(Previously PA 5) Philadelphia, Wilmington, Trenton
PA 2-4	(Previously PA 8) Harrisburg, Lancaster, York
PA 2-5	(Previously PA 7) Allentown-Bethlehem-Easton, Reading
PA 2-6	(Previously Market Area 31) Northeast Pennsylvania, Binghamton, Elmira
PA 2-7	(Previously PA 9) Syracuse, Utica-Rome, Albany-Schenectady-Troy
PA 2-8	(Previously PA 10) Buffalo, Rochester
PA 2-9	(Previously PA 12) Pittsburgh, Steubenville-Weirton, Wheeling

EAST NORTH CENTRAL

PA 3-1	(Previously PA 11) Cleveland, Akron, Canton, Lorain-Elyria, Youngstown-Warren, Erie
PA 3-2	(Previously Market Area 34) Columbus, Springfield
PA 3-3	(Previously PA 14) Cincinnati, Dayton, Hamilton-Middletown
PA 3-4	(Previously PA 13) Detroit, Flint, Toledo, Ann Arbor
PA 3-5	Lansing-East Lansing, Kalamazoo-Portage, Jackson, Battle Creek
PA 3-6	(Previously Market Area 35) Grand Rapids, Muskegon-Norton Shores-Muskegon Heights
PA 3-7	(Previously PA 28) Indianapolis, Anderson, Muncie
PA 3-8	(Previously PA 15) Chicago, Gary-Hammond-East Chicago
PA 3-9	(Previously PA 16) Milwaukee, Kenosha, Racine

WEST NORTH CENTRAL

PA 4-1	(Previously PA 18) St. Louis
PA 4-2	(Previously PA 27) Kansas City, Lawrence, St. Joseph, Topeka
PA 4-3	(Previously PA 17) Minneapolis-St. Paul

SOUTH ATLANTIC

PA 5-1	(Previously PA 6) Baltimore
PA 5-2	(Previously Market Area 32) Washington, D.C.-Md.-Va.

SOUTH ATLANTIC—Continued

PA 5-3	(Previously Market Area 33) Norfolk-Virginia Beach-Portsmouth, Newport News-Hampton, Petersburg-Colonial Heights-Hopewell, Richmond
PA 5-4	Greensboro-Winston Salem-High Point, Burlington, Raleigh-Durham
PA 5-5	Charlotte-Gastonia, Greenville-Spartanburg
PA 5-6	(Previously PA 19) Atlanta
PA 5-7	(Previously Market Area 43) Daytona Beach, , Melbourne-Titusville-Cocoa, Orlando, Lakeland-Winter Haven, Tampa-St. Petersburg
PA 5-8	(Previously Market Area 41) Miami, Ft. Lauderdale-Hollywood, West Palm Beach-Boca Raton

EAST SOUTH CENTRAL

PA 6-1	(Previously Market Area 37) Louisville
PA 6-2	(Previously Market Area 38) Nashville-Davidson, Clarksville-Hopkinsville
PA 6-3	(Previously Market Area 39) Memphis
PA 6-4	(Previously Market Area 42) Birmingham, Tuscaloosa, Anniston, Gadsden

WEST SOUTH CENTRAL

PA 7-1	(Previously Market Areas 44 and 45) Baton Rouge, New Orleans, Biloxi-Gulfport, Pascagoula-Moss Point, Mobile, Pensacola
PA 7-2	(Previously PA 21) Houston, Beaumont-Port Arthur-Orange, Galveston-Texas City
PA 7-3	(Previously Market Area 49) Austin, San Antonio
PA 7-4	(Previously PA 20) Dallas-Fort Worth
PA 7-5	(Previously Market Area 48) Tulsa, Oklahoma City

MOUNTAIN

PA 8-1	(Previously PA 22) Denver-Boulder, Colorado Springs
PA 8-2	(Previously Market Area 50) Salt Lake City-Ogden, Provo-Orem
PA 8-3	(Previously Market Area 51) Phoenix, Tucson

PACIFIC

PA 9-1	(Previously PA 23) Seattle-Everett, Tacoma
PA 9-2	(Previously Market Area 52) Portland, Salem
PA 9-3	(Previously PA 24) San Francisco-Oakland, Vallejo-Fairfield-Napa, San Jose, Santa Rosa, Santa Cruz
PA 9-4	(Previously Market Area 53) Sacramento, Stockton, Modesto
PA 9-5	(Previously PA 25) Los Angeles-Long Beach, Anaheim-Santa Ana-Garden Grove, Riverside-San Bernardino-Ontario, Oxnard-Simi Valley-Ventura
PA 9-6	(Previously Market Area 55) San Diego

Source: USDOC 1981a.

C.1.3 Locate Values for Tons and Ton-Miles Shipped in CTS Publications

Once the commodity type and required geographic specificity of the search are established, specific values for tons and ton-miles shipped must be located in the appropriate tables of the CTS reports. The source of this information differs with each method. However, a concern common to the three methods is that the values obtained for tons and ton-miles shipped must be significant. These data are reported in thousands of tons shipped and millions of ton-miles shipped (USDOC 1981a). If the reported quantity for tons or ton-miles for a specific combination of TCC code and geographic specificity is less than one-half of the unit of measure (i.e., less than 500 tons shipped or less than 500,000 ton-miles), those values are considered insignificant. In such cases, a more general TCC code (one with fewer digits, see Section C.1.1) or a larger geographic area should be selected.

C.1.4 Calculate the Average Shipping Distance of the Chemical

For each mode of transportation, the average shipping distance is computed by dividing the value obtained from the CTS tables for ton-miles shipped by the value for tons shipped:

$$\text{Average distance shipped (in miles)} = \frac{\text{ton-miles shipped}}{\text{tons shipped}} .$$

For shipments by truck, a weighted average shipping distance can be calculated from the values obtained for the two major truck categories included in the CTS reports, that is, motor carriers (ICC and non-ICC) and private truck. In order to calculate the average shipping distance for trucks, multiply the average shipping distance (ton-miles/tons shipped) for each truck category by the fraction of the total quantity shipped by truck that is represented by that category. The sum of the products for the two categories is the weighted average shipping distance for truck shipments.

C.2 Selecting a Method

Of the three methods presented in this appendix, the reader should select the method appropriate for the level of information available on shipment of the chemical, as follows:

Method	Average quantity/ shipment	Origin of shipments	Destination of shipments
C-1	Unknown	Unknown	Unknown
C-2	Unknown	Known	Unknown
C-3	Known	Unknown	Unknown

The more detailed the available information, the more accurately the average shipping distance can be estimated.

C.3 Descriptions of the Methods

This section of the appendix describes each of the methods available for estimating shipping distance of a chemical.

C.3.1 Method C-1. Estimation of the average shipping distance of a chemical when the average quantity per shipment, the origin of shipment, and destination of shipments are all unknown. The average shipping distance is derived in 4 steps, as follows:

(a) Match the STCC code for the chemical (determined in Step 1 of the general method, Section 3.1 of this report) with the most closely related TCC code available in Table 2 of the CTS Summary (USDOC 1981a).

(b) The origin of shipments is unknown, and therefore the shipping data in the CTS Summary (USDOC 1981a) are used.

(c) For each mode of transportation, identify from Table 2 of the CTS Summary the values for tons shipped (Table 2, Column B) and ton-miles (Table 2, Column C).

(d) Divide the value for ton-miles for each mode of transportation by the corresponding value for tons shipped. The quotient is the average shipping distance of the chemical by that mode of transportation.

C.3.2 Method C-2. Estimation of the average shipping distance of a chemical when the origin is known but the average quantity per shipment and the destination of shipments are unknown.

If manufacture of a chemical is restricted to a particular geographic region of the country, the Commodity Transportation Survey, Geographic Area Series (USDOC 1981b), can be used as a source of information for estimating the average shipment distance of the chemical. The steps of the method are as follows:

(a) Match the STCC code for the chemical (determined in Step 1 of the general method, Section 3.1 of this report) with the most closely related TCC code available in Table 1 of the Commodity Transportation Survey, Geographic Area Series (USDOC 1981b).

(b) Identify the manufacturing location using the PRODUCTS section of the SRI Directory of Chemical Producers (see SRI 1986). Identify the most specific geographic area of origin available in the CTS Geographic Area Series (USDOC 1981b) that corresponds to the manufacturing location.

(c) For the geographic area and TCC code selected, identify in Table 1 of the CTS Geographic Area Series the values for tons shipped and ton-miles shipped. Ascertain that these values are significant (see Section C.1.3).

(d) For each mode of transportation, divide the value for ton-miles shipped by the corresponding value for tons shipped. The quotient is the average shipping distance of the chemical for that mode of transportation.

C.3.3 Method C-3. Estimation of the average shipping distance of a chemical when the average quantity per shipment is known but the origin and destination of shipments are unknown.

This method allows greater specificity in the calculation of average shipping distance by using data available for specific weight intervals of commodity shipments that are presented in the CTS Commodity Series (USDOC 1981c). It does not require information on the origin of shipments.

(a) Match the STCC code for the chemical (determined in Step 1 of the general method, Section 3.1 of this report) with the most closely related TCC code available in Table 3 of the CTS Commodity Series (USDOC 1981c).

(b) The origin of shipments is unknown; therefore, the U.S. summary data in the CTS Commodity Series (USDOC 1981c) are used.

(c) Identify the average quantity per shipment determined in Step 5 of the general method, Section 3.1 of this report. Then, locate a corresponding weight interval of shipments listed for the selected TCC commodity code in Table 7 of the CTS Commodity Series. For each mode of transportation, locate the values for tons shipped and ton-miles shipped for that weight interval.

(d) Divide the value for ton-miles shipped by the corresponding value for tons shipped for each mode of transportation. The quotient is the average shipping distance of the chemical for the selected weight interval and mode of transportation.